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<b>(54) Title:</b> STIMULUS-INDUCIBLE I (KAPPA)B KINASE [IKK] SIGNALSOME  <b>(57) Abstract</b>  Compositions and methods are provided for treating NF- $\kappa$ B-related conditions. In particular, the invention provides a stimulus-inducible IKK signalsome, and components and variants thereof. An IKK signalsome or component thereof may be used, for example, to identify antibodies and other modulating agents that inhibit or activate signal transduction via the NF- $\kappa$ B cascade. IKK signalsome, components thereof and/or modulating agents may also be used for the treatment of diseases associated with NF- $\kappa$ B activation.		

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Description**STIMULUS-INDUCIBLE I (KAPPA)B KINASE (IKK) SIGNALSOME**

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Technical Field

The present invention relates generally to compositions and methods useful for the study of cascades leading to the activation of nuclear factor  $\kappa$ B (NF- $\kappa$ B) and for treating diseases associated with such pathways. The invention is more particularly related to a stimulus-inducible I $\kappa$ B kinase (IKK) signalsome, component I $\kappa$ B kinases and variants of such kinases. The present invention is also related to the use of a stimulus-inducible IKK signalsome or I $\kappa$ B kinase to identify antibodies and other agents that inhibit or activate signal transduction via the NF- $\kappa$ B pathway.

15 Background of the Invention

Transcription factors of the NF $\kappa$ B/Rel family are critical regulators of genes involved in inflammation, cell proliferation and apoptosis (for reviews, see Verma et al., *Genes Dev.* 9:2723-35, 1995; Siebenlist, *Biochim. Biophys. Acta* 1332:7-13, 1997; Baeuerle and Henkel, *Ann. Rev. Immunol.* 12:141-79, 1994; Barnes and Karin, *New Engl. J. Med.* 336, 1066-71, 1997; Baeuerle and Baltimore, *Cell* 87:13-20, 1996; Grilli et al., *NF- $\kappa$ B and Rel: Participants in a multiform transcriptional regulatory system* (Academic Press, Inc., 1993), vol. 143; Baichwal and Baeuerle, *Curr. Biol.* 7:94-96, 1997). The prototype member of the family, NF $\kappa$ B, is composed of a dimer of p50 NF $\kappa$ B and p65 RelA (Baeuerle and Baltimore, *Cell* 53:211-17, 1988; Baeuerle and Baltimore, *Genes Dev.* 3:1689-98, 1989). NF- $\kappa$ B plays a pivotal role in the highly specific pattern of gene expression observed for immune, inflammatory and acute phase response genes, including interleukin 1, interleukin 8, tumor necrosis factor and certain cell adhesion molecules.

Like other members of the Rel family of transcriptional activators, NF- $\kappa$ B is sequestered in an inactive form in the cytoplasm of most cell types. A variety of extracellular stimuli including mitogens, cytokines, antigens, stress inducing agents, UV

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light and viral proteins initiate a signal transduction pathway that ultimately leads to NF- $\kappa$ B release and activation. Thus, inhibitors and activators of the signal transduction pathway may be used to alter the level of active NF- $\kappa$ B, and have potential utility in the treatment of diseases associated with NF- $\kappa$ B activation.

5           Activation of NF $\kappa$ B in response to each of these stimuli is controlled by an inhibitory subunit, I $\kappa$ B, which retains NF $\kappa$ B in the cytoplasm. I $\kappa$ B proteins, of which there are six known members, each contain 5-7 ankyrin-like repeats required for association with the NF $\kappa$ B/Rel dimer and for inhibitory activity (*see* Beg et al., *Genes Dev.* 7, 2064-70, 1993; Gilmore and Morin, *Trends Genet.* 9, 427-33, 1993; Diaz-Meco et al., *Mol. Cell. Biol.* 13:4770-75, 1993; Haskill et al., *Cell* 65:1281-89, 1991). I $\kappa$ B proteins include I $\kappa$ B $\alpha$  and I $\kappa$ B $\beta$ .

NF $\kappa$ B activation involves the sequential phosphorylation, ubiquitination, and degradation of I $\kappa$ B. Phosphorylation of I $\kappa$ B is highly specific for target residues. For example, phosphorylation of the I $\kappa$ B protein I $\kappa$ B $\alpha$  takes place at serine residues S32 and  
15   S36, and phosphorylation of I $\kappa$ B $\beta$  occurs at serine residues S19 and S23. The choreographed series of modification and degradation steps results in nuclear import of transcriptionally active NF $\kappa$ B due to the exposure of a nuclear localization signal on NF $\kappa$ B that was previously masked by I $\kappa$ B (Beg et al., *Genes Dev.* 6:1899-1913, 1992). Thus, NF $\kappa$ B activation is mediated by a signal transduction cascade that includes one or  
20   more specific I $\kappa$ B kinases, a linked series of E1, E2 and E3 ubiquitin enzymes, the 26S proteasome, and the nuclear import machinery. The phosphorylation of I $\kappa$ B is a critical step in NF- $\kappa$ B activation, and the identification of an I $\kappa$ B kinase, as well as proteins that modulate its kinase activity, would further the understanding of the activation process, as well as the development of therapeutic methods.

25           Several protein kinases have been found to phosphorylate I $\kappa$ B *in vitro*, including protein kinase A (Ghosh and Baltimore, *Nature* 344:678-82, 1990), protein kinase C (Ghosh and Baltimore, *Nature* 344:678-82, 1990) and double stranded RNA-dependent protein kinase (Kumar et al., *Proc. Natl. Acad. Sci. USA* 91:6288-92, 1994). Constitutive phosphorylation of I $\kappa$ B $\alpha$  by casein kinase II has also  
30   been observed (*see* Barroga et al., *Proc. Natl. Acad. Sci. USA* 92:7637-41, 1995). None



of these kinases, however appear to be responsible for *in vivo* activation of NF- $\kappa$ B. For example, phosphorylation of I $\kappa$ B $\alpha$  *in vitro* by protein kinase A and protein kinase C prevent its association with NF- $\kappa$ B, and phosphorylation by double-stranded RNA-dependent protein kinase results in dissociation of NF- $\kappa$ B. Neither of these conform to the effect of phosphorylation *in vivo*, where I $\kappa$ B $\alpha$  phosphorylation at S32 and S36 does not result in dissociation from NF- $\kappa$ B.

Other previously unknown proteins with I $\kappa$ B kinase activity have been reported, but these proteins also do not appear to be significant activators *in vivo*. A putative I $\kappa$ B $\alpha$  kinase was identified by Kuno et al., *J. Biol. Chem.* 270:27914-27919, 1995, but that kinase appears to phosphorylate residues in the C-terminal region of I $\kappa$ B $\alpha$ , rather than the S32 and S36 residues known to be important for *in vivo* regulation. Diaz-Meco et al., *EMBO J.* 13:2842-2848, 1994 also identified a 50 kD I $\kappa$ B kinase, with uncharacterized phosphorylation sites. Schouten et al., *EMBO J.* 16:3133-44, 1997 identified p90<sup>rski</sup> as a putative I $\kappa$ B $\alpha$  kinase; however, p90<sup>rski</sup> is only activated by TPA and phosphorylates I $\kappa$ B $\alpha$  only on Ser32, which is insufficient to render I $\kappa$ B $\alpha$  a target for ubiquitination. Finally, Chen et al, *Cell* 84:853-862, 1996 identified a kinase that phosphorylates I $\kappa$ B $\alpha$ , but that kinase was identified using a non-physiological inducer of I $\kappa$ B $\alpha$  kinase activity and requires the addition of exogenous factors for *in vitro* phosphorylation.

Accordingly, there is a need in the art for an I $\kappa$ B kinase that possesses the substrate specificity and other properties of the *in vivo* kinase. There is also a need for improved methods for modulating the activity of proteins involved in activation of NF- $\kappa$ B, and for treating diseases associated with NF- $\kappa$ B activation. The present invention fulfills these needs and further provides other related advantages.

#### Summary of the Invention

Briefly stated, the present invention provides compositions and methods employing a large, multi-subunit IKK signalsome, or a component or variant thereof. In one aspect, the present invention provides an IKK signalsome capable of specifically

phosphorylating I $\kappa$ B $\alpha$  at residues S32 and S36, and I $\kappa$ B $\beta$  at residues 19 and 23, without the addition of exogenous cofactors.

In a further related aspect, a polypeptide comprising a component of an IKK signalsome, or a variant of such a component, is provided, wherein the component  
5 has a sequence recited in SEQ ID NO:9. An isolated DNA molecule and recombinant expression vector encoding such a polypeptide, as well as a transfected host cell, are also provided.

In another aspect, methods for preparing an IKK signalsome are provided, comprising combining components of an IKK signalsome in a suitable buffer.

10 In yet another aspect, methods are provided for phosphorylating a substrate of an IKK signalsome, comprising contacting a substrate with an IKK signalsome or a component thereof, and thereby phosphorylating the substrate.

In a further aspect, the present invention provides a method for screening for an agent that modulates IKK signalsome activity, comprising: (a) contacting a  
15 candidate agent with an IKK signalsome, wherein the step of contacting is carried out under conditions and for a time sufficient to allow the candidate agent and the IKK signalsome to interact; and (b) subsequently measuring the ability of the candidate agent to modulate IKK signalsome activity.

Within a related aspect, the present invention provides methods for  
20 screening for an agent that modulates IKK signalsome activity, comprising: (a) contacting a candidate agent with a polypeptide comprising a component of an IKK signalsome as described above, wherein the step of contacting is carried out under conditions and for a time sufficient to allow the candidate agent and the polypeptide to interact; and (b) subsequently measuring the ability of the candidate agent to modulate the  
25 ability of the polypeptide to phosphorylate an I $\kappa$ B protein.

In another aspect, an antibody is provided that binds to a component (*e.g.*, IKK-1 and/or IKK-2) of an IKK signalsome, where the component is capable of phosphorylating I $\kappa$ B $\alpha$ .

In further aspects, the present invention provides methods for modulating  
30 NF- $\kappa$ B activity in a patient, comprising administering to a patient an agent that modulates I $\kappa$ B kinase activity in combination with a pharmaceutically acceptable carrier. Methods

are also provided for treating a patient afflicted with a disorder associated with the activation of IKK signalsome, comprising administering to a patient a therapeutically effective amount of an agent that modulates I $\kappa$ B kinase activity in combination with a pharmaceutically acceptable carrier.

5 In yet another aspect, a method for detecting IKK signalsome activity in a sample is provided, comprising: (a) contacting a sample with an antibody that binds to an IKK signalsome under conditions and for a time sufficient to allow the antibody to immunoprecipitate an IKK signalsome; (b) separating immunoprecipitated material from the sample; and (c) determining the ability of the immunoprecipitated material to  
10 specifically phosphorylate an I $\kappa$ B protein with *in vivo* specificity. Within one such embodiment, the ability of the immunoprecipitated material to phosphorylate I $\kappa$ B $\alpha$  at residues S32 and/or S36 is determined.

In a related aspect, a kit for detecting IKK signalsome activity in a sample is provided, comprising an antibody that binds to an IKK signalsome in combination with  
15 a suitable buffer.

In a further aspect, the present invention provides a method for identifying an upstream kinase in the NF- $\kappa$ B signal transduction cascade, comprising evaluating the ability of a candidate upstream kinase to phosphorylate an IKK signalsome, a component thereof or a variant of such a component.

20 A method for identifying a component of an IKK signalsome is also provided, comprising: (a) isolating an IKK signalsome; (b) separating the signalsome into components, and (c) obtaining a partial sequence of a component.

In yet another aspect, a method is provided for preparing an IKK signalsome from a biological sample, comprising: (a) separating a biological sample into  
25 two or more fractions; and (b) monitoring I $\kappa$ B kinase activity in the fractions.

These and other aspects of the present invention will become apparent upon reference to the following detailed description and attached drawings. All references disclosed herein are hereby incorporated by reference in their entirety as if each was incorporated individually.

### Brief Description of the Drawings

Figures 1A-1C are autoradiograms depicting the results of immunoblot analyses. Figure 1A shows the recruitment of I $\kappa$ B $\alpha$  into a high molecular weight complex upon stimulation. Cytoplasmic extracts of either unstimulated or PMA(50 ng/ml)- and PHA(1  $\mu$ g/ml)-stimulated (10 min) Jurkat cells were fractionated on a gel filtration column. I $\kappa$ B $\alpha$  was visualized by immunoblot analysis. The upper panel shows the elution profile of unstimulated cells, and the lower panel shows the elution profile of PMA/PHA-stimulated cells. Molecular weight standards are indicated by arrows on the top.

Figure 1B shows that the stimulus-dependent I $\kappa$ B $\alpha$  kinase activity chromatographs as a high molecular weight complex, M<sub>r</sub> 500-700 kDa. Whole cell extract of TNF $\alpha$ -stimulated (20 ng/ml, 7 min) HeLa S3 cells was fractionated on a Superdex 200 gel filtration column and monitored for I $\kappa$ B $\alpha$  kinase activity. Phosphorylation of the GST I $\kappa$ B $\alpha$  1-54 (wildtype) substrate is indicated by an arrow to the right. Molecular weight standards are indicated by arrows on the top.

Figure 1C illustrates the identification of proteins that co-chromatograph with the IKK signalsome. IKK signalsome was partially purified from extracts of TNF $\alpha$ -stimulated HeLa S3 cells by sequential fractionation on a Q Sepharose, Superdex 200, Mono Q, and Phenyl Superose columns. Phenyl Superose fractions containing the peak of IKK signalsome activity were subjected to western blot analysis using several different antibodies as indicated to the left of each respective panel. The level of IKK signalsome activity is indicated in the upper shaded area by increasing number of (+)'s.

Figure 2 is a flow chart depicting a representative purification procedure for the preparation of an IKK signalsome.

Figures 3A and 3B are autoradiograms that show the results of a Western blot analysis of the levels of I $\kappa$ B $\alpha$  in HeLa S3 cytoplasmic extracts following gel filtration. The extracts were prepared from cells that were (Figure 3B) and were not (Figure 3A) exposed to TNF $\alpha$ .

Figures 4A and 4B are autoradiograms depicting the results of an *in vitro* kinase assay in which the ability of the above cell extracts to phosphorylate the N-terminal portion of I $\kappa$ B $\alpha$  was evaluated. Figure 4A shows the results employing an

extract from cells that were not treated with  $\text{TNF}\alpha$ , and Figure 4B shows the results when the cells were treated with  $\text{TNF}\alpha$ .

Figures 5A and 5B are autoradiograms depicting the results of an *in vitro* kinase assay using a cytoplasmic extract of  $\text{TNF}\alpha$ -treated HeLa S3 cells, where the extract is subjected to Q Sepharose fractionation. The substrate was the truncated  $\text{I}\kappa\text{B}\alpha$  (residues 1 to 54), with Figure 5A showing the results obtained with the wild type  $\text{I}\kappa\text{B}\alpha$  sequence and Figure 5B presenting the results obtained using a polypeptide containing threonine substitutions at positions 32 and 36.

Figures 6A and 6B are autoradiograms depicting the results of an *in vitro* kinase assay using a cytoplasmic extract of  $\text{TNF}\alpha$ -treated HeLa S3 cells, where the extract was subjected in series to chromatographic fractionation by Q Sepharose, Superdex 200, Mono Q Sepharose and Phenyl Superose. The substrate was the truncated  $\text{I}\kappa\text{B}\alpha$  (residues 1 to 54), with Figure 6A showing the results obtained with the wild type  $\text{I}\kappa\text{B}\alpha$  sequence and Figure 6B presenting the results obtained using a polypeptide containing threonine substitutions at positions 32 and 36.

Figure 7 is an autoradiogram showing the results of immunokinase assays (using anti-MKP-1 antibody) performed using cytoplasmic extracts of  $\text{TNF}\alpha$ -treated HeLa S3 cells following gel filtration. The assay was performed using the substrates GST- $\text{I}\kappa\text{B}\alpha$ 1-54 wildtype (lane 1) and GST-  $\text{I}\kappa\text{B}\alpha$ 1-54 S32/36 to T (lane 2). The positions of  $\text{I}\kappa\text{B}\alpha$  and GST- $\text{I}\kappa\text{B}\alpha$  1-54 are indicated on the left.

Figures 8A-8C are autoradiograms depicting the results of immunoblot analyses. In Figure 8A, the upper panel presents a time course for the induction of signalsome activity. Anti MKP-1 immune precipitates from extracts of HeLa S3 cells stimulated with  $\text{TNF}\alpha$  (20 ng/ml) for the indicated times, were assayed for IKK signalsome activity by standard immune complex kinase assays. 4  $\mu\text{g}$  of either GST  $\text{I}\kappa\text{B}\alpha$  1-54 WT (wildtype) or the GST  $\text{I}\kappa\text{B}\alpha$  1-54 S32/36 to T mutant (S>T) were used as the substrates. In the lower panel, HeLa cell extracts prepared as described in the upper panel were examined by western blot analysis for  $\text{I}\kappa\text{B}\alpha$  degradation.  $\text{I}\kappa\text{B}\alpha$  supershifting phosphorylation can be seen after 3 and 5 minutes of stimulation followed by the disappearance of  $\text{I}\kappa\text{B}\alpha$ .

Figure 8B illustrates the stimulus-dependent activation of IKK signalsome, which is blocked by TPCK. Anti-MKP-1 immunoprecipitates from cell extracts of HeLa S3 cells either stimulated for 7 min with TNF $\alpha$  (20 ng/ml, lane 2 and 6), IL-1 (10 ng/ml, lane 3), PMA (50 ng/ml, lane 4) or pretreated for 30 min with TPCK (15  $\mu$ M, lane 7) prior to TNF $\alpha$ -induction were examined for IKK signalsome activity. GST I $\kappa$ B $\alpha$  1-54 WT (4  $\mu$ g) was used as a substrate.

Figure 8C illustrates the ability of IKK signalsome to specifically phosphorylate serines 32 and 36 of the I $\kappa$ B $\alpha$  holoprotein in the context of a RelA:I $\kappa$ B $\alpha$  complex. Anti-MKP-1 immunoprecipitates from cell extracts of HeLa S3 cells stimulated with TNF $\alpha$  (20 ng/ml, 7 min) were examined for their ability to phosphorylate baculoviral expressed RelA:I $\kappa$ B $\alpha$  complex containing either the I $\kappa$ B $\alpha$  WT (lane 3) or I $\kappa$ B $\alpha$  S32/36 to A mutant (lane 4) holoprotein. The specific substrates used are indicated on the top. Positions of the phosphorylated substrates are indicated by arrows to the left of the panel.

Figure 9A is an autoradiogram depicting the results of an immunokinase assay in which peptides are phosphorylated by the IKK signalsome. In the top panel, I $\kappa$ B $\alpha$ (21-41) peptides that were unphosphorylated or chemically phosphorylated on either Ser-32 or Ser-36 were incubated with the IKK signalsome in the presence of  $\gamma$ -[ $^{32}$ P]-ATP. The doubly phosphorylated peptide P32,36 was not phosphorylated by the IKK signalsome, and the unrelated c-Fos(222-241) phosphopeptide with free serine and threonine residues did not function as a signalsome substrate.

Figure 9B is a graph illustrating the inhibition of phosphorylation of GST-I $\kappa$ B $\alpha$  (1-54) by I $\kappa$ B $\alpha$ (21-41) peptides. I $\kappa$ B $\alpha$ (21-41) peptide P32,36 inhibits GST-I $\kappa$ B $\alpha$  (1-54) as a product inhibitor with a  $K_i$  value of 14  $\mu$ M. The unrelated phosphopeptide c-Fos(222-241) does not function as an inhibitor. This assay only detects precipitated  $^{32}$ P-labeled-proteins, not  $^{32}$ P-labeled-peptides. Addition of the singly- or non-phosphorylated I $\kappa$ B $\alpha$ (21-41) peptides results in less phosphorylation of GST-I $\kappa$ B $\alpha$  (1-54) and apparent inhibition.

Figure 10 is an autoradiogram showing the results of a western blot analysis of the level of ubiquitin within a stimulus-inducible I $\kappa$ B kinase complex. Lane 1 shows the detection of 100 ng ubiquitin, Lane 2 shows 10 ng ubiquitin and Lane 3 shows

3.4  $\mu$ g of IKK signalsome purified through the phenyl superose step (sufficient quantities for 10 kinase reactions). The position of ubiquitin is shown by the arrow on the left.

Figure 11A illustrates a procedure for purification of the IKK signalsome. A whole cell extract was prepared from TNF $\alpha$ -stimulated (20 ng/ml, 7 minute induction) HeLa S3 cells (1.2 g total protein). The IKK signalsome was then immunoprecipitated from the extract using anti-MKP-1 antibodies, washed with buffer containing 3.5 M urea and eluted overnight at 4°C in the presence of excess MKP-1 specific peptide. Eluted IKK signalsome was then fractionated on a Mono Q column, I $\kappa$ B kinase active fractions were pooled, concentrated and subjected to preparative SDS-PAGE. Individual protein bands were excised and submitted for peptide sequencing.

Figure 11B is a photograph showing Mono Q fractions containing active IKK signalsome activity following SDS-PAGE and a standard silver stain protocol. Peak activity of IKK signalsome activity is represented in lanes 3, 4, and 5. Protein bands corresponding to IKK-1 and IKK-2 are indicated to the left of the figure. Molecular weight standards (kDa) are indicated to the left of the figure.

Figures 12A and 12B are mass spectra obtained during sequencing of IKK-2 by nanoelectrospray mass spectrometry. Figure 12A shows part of the mass spectrum of the unseparated mixture of tryptic peptides resulting from in-gel digestion of the IKK-2 band in Figure 11B. Figure 12B shows a tandem mass spectrum of the peak at m/z 645.2.

Figure 13A illustrates the amino acid sequence of IKK-1 and IKK-2. Symbols: arrows, boundaries of the kinase domain; underlined, peptide sequences identified by nanoelectrospray mass spectrometry; asterisks, indicates leucines comprising the leucine zipper motif; bold face, indicate amino acid identities conserved between IKK-1 and IKK-2; highlighted box, Helix-loop-helix domain; dashes, a gap inserted to optimize alignment.

Figure 13B is an autoradiogram depicting the results of Northern blot analysis of IKK-2 mRNA in adult human tissue. The source of the tissue is indicated at the top. Probes spanning the coding region of human IKK-2 and  $\beta$ -actin cDNA were used and are indicated to the left. Molecular weight standards are indicated to the right.

Figure 14A is an autoradiogram depicting the results of kinase assays using IKK-1 and IKK-2. IKK-1 and IKK-2 were immunoprecipitated from rabbit reticulocyte lysates phosphorylate I $\kappa$ B $\alpha$  and I $\kappa$ B $\beta$ . Either HA-tagged IKK-1 (lane 1) or Flag-tagged IKK-2 (lane 2) were translated in rabbit reticulocyte lysates, immunoprecipitated, and examined for their ability to phosphorylate GST I $\kappa$ B $\alpha$  1-54 WT and GST I $\kappa$ B $\beta$  1-44 as indicated by an arrow to the left. IKK-1 (lane 1) undergoes significant autophosphorylation in contrast to IKK-2 (lane 2) which is identified only with longer exposure times.

Figures 14B and 14C are micrographs illustrating the results of assays to evaluate the ability of kinase-inactive mutants of IKK-1 and IKK-2 to inhibit RelA translocation in TNF $\alpha$ -stimulated HeLa cells. HeLa cells were transiently transfected with either HA-tagged IKK-1 K44 to M mutant (14B) or Flag-tagged IKK-2 K44 to M mutant (14C) expression vectors. 36 hours post-transfection cells were either not stimulated (Unstim) or TNF $\alpha$ -stimulated (20 ng/ml) for 30 min (TNF $\alpha$ ), as indicated to the right of the figure. Cells were then subjected to immunofluorescence staining using anti-HA or anti-Flag antibodies to visualize expression of IKK-1 K44 to M or IKK-2 K44 to M, respectively. Stimulus-dependent translocation of Rel A was monitored using anti-Rel A antibodies. Antibodies used are indicated to the top of the figure. IKK mutant transfected is indicated to the left of the figure.

Figures 15A and 15B are autoradiograms of immunoprecipitated IKK-1 and IKK-2 following *in vitro* translation. In Figure 15A, HA-tagged IKK-1 and Flag-tagged IKK-2 were *in vitro* translated in wheat germ lysates either separately or in combination, as indicated. The programmed translation mix was then subjected to immunoprecipitation using the indicated antibody. The samples were run on SDS-PAGE and subjected to autoradiography. In Figure 15B, HA-tagged IKK-1 and Flag-tagged IKK-2 were *in vitro* translated in rabbit reticulocyte lysates either separately or in combination, as indicated. The programmed translation mix was then subjected to immunoprecipitation using the indicated antibody. The samples were run on SDS-PAGE and subjected to autoradiography. The results show that IKK-1 and IKK-2 coprecipitate when translated in rabbit reticulocyte lysates.



### Detailed Description of the Invention

As noted above, the present invention is generally directed to compositions and methods for modulating (*i.e.*, stimulating or inhibiting) signal transduction leading to NF- $\kappa$ B activation. In particular, the present invention is directed to compositions comprising an  $\kappa$ B kinase (IKK) signalsome (also referred to herein as a "stimulus-inducible  $\kappa$ B kinase complex" or " $\kappa$ B kinase complex") that is capable of stimulus-dependent phosphorylation of  $\kappa$ B $\alpha$  and  $\kappa$ B $\beta$  on the two N-terminal serine residues critical for the subsequent ubiquitination and degradation *in vivo*. Such stimulus-dependent phosphorylation may be achieved without the addition of exogenous cofactors. In particular, an IKK signalsome specifically phosphorylates  $\kappa$ B $\alpha$  (SEQ ID NO:1) at residues S32 and S36 and phosphorylates  $\kappa$ B $\beta$  (SEQ ID NO:2) at residues S19 and S23. The present invention also encompasses compositions that contain one or more components of such an IKK signalsome, or variants of such components. Preferred components, referred to herein as "IKK signalsome kinases" " $\kappa$ B kinases" or IKKs) are kinases that, when incorporated into an IKK signalsome, are capable of phosphorylating  $\kappa$ B $\alpha$  at S32 and S36. Particularly preferred components are IKK-1 (SEQ ID NO:10) and IKK-2 (SEQ ID NO:9).

An IKK signalsome and/or  $\kappa$ B kinase may generally be used for phosphorylating a substrate (*i.e.*, an  $\kappa$ B, such as  $\kappa$ B $\alpha$ , or a portion or variant thereof that can be phosphorylated at those residues that are phosphorylated *in vivo*) and for identifying modulators of  $\kappa$ B kinase activity. Such modulators and methods employing them for modulating  $\kappa$ B $\alpha$  kinase activity, *in vivo* and/or *in vitro*, are also encompassed by the present invention. In general, compositions that inhibit  $\kappa$ B kinase activity may inhibit  $\kappa$ B phosphorylation, or may inhibit the activation of an  $\kappa$ B kinase and/or IKK signalsome.

An IKK signalsome has several distinctive properties. Such a complex is stable (*i.e.*, its components remain associated following purification as described herein) and has a high-molecular weight (about 500-700 kD, as determined by gel filtration chromatography). As shown in Figures 3 (A and B) and 4 (A and B),  $\kappa$ B kinase activity of an IKK signalsome is "stimulus-inducible" in that it is stimulated by TNF $\alpha$  (*i.e.*,

treatment of cells with TNF $\alpha$  results in increased I $\kappa$ B kinase activity and I $\kappa$ B degradation) and/or by one or more other inducers of NF- $\kappa$ B, such as IL-1, LPS, TPA, UV irradiation, antigens, viral proteins and stress-inducing agents. The kinetics of stimulation by TNF $\alpha$  correspond to those found *in vivo*. I $\kappa$ B kinase activity of an IKK signalsome is also specific for S32 and S36 of I $\kappa$ B $\alpha$ . As shown in Figures 5 (A and B) and 6 (A and B), an IKK signalsome is capable of phosphorylating a polypeptide having the N-terminal sequence of I $\kappa$ B $\alpha$  (GST-I $\kappa$ B $\alpha$ 1-54; SEQ ID NO:3), but such phosphorylation cannot be detected in an I $\kappa$ B $\alpha$  derivative containing threonine substitutions at positions 32 and 36. In addition, I $\kappa$ B kinase activity is strongly inhibited by a doubly phosphorylated I $\kappa$ B $\alpha$  peptide (*i.e.*, phosphorylated at S32 and S36), but not by an unrelated c-fos phosphopeptide that contains a single phosphothreonine. A further characteristic of an IKK signalsome is its ability to phosphorylate a substrate *in vitro* in a standard kinase buffer, without the addition of exogenous cofactors. Free ubiquitin is not detectable in preparations of IKK signalsome (*see* Figure 10), even at very long exposures. Accordingly an IKK signalsome differs from the ubiquitin-dependent I $\kappa$ B $\alpha$  kinase activity described by Chen et al., *Cell* 84:853-62, 1996.

An IKK signalsome may be immunoprecipitated by antibodies raised against MKP-1 (MAP kinase phosphatase-1; Santa Cruz Biotechnology, Inc., Santa Cruz, CA #SC-1102), and its activity detected using an *in vitro* I $\kappa$ B $\alpha$  kinase assay. However, as discussed further below, MKP-1 does not appear to be a component of I $\kappa$ B kinase complex. The substrate specificity of the immunoprecipitated IKK signalsome is maintained (*i.e.*, there is strong phosphorylation of wildtype GST-I $\kappa$ B $\alpha$  1-54 (SEQ ID NO:3) and GST-I $\kappa$ B $\beta$  1-44 (SEQ ID NO:4), and substantially no detectable phosphorylation of GST-I $\kappa$ B $\alpha$  1-54 in which serines 32 and 36 are replaced by threonines (GST-I $\kappa$ B $\alpha$  S32/36 to T; SEQ ID NO:5) or GST-I $\kappa$ B $\beta$  1-44 in which serines 19 and 23 are replaced by alanines (GST-I $\kappa$ B $\beta$  1-44 S19/23 to A; SEQ ID NO:6)).

An IKK signalsome may be isolated from human or other cells, and from any of a variety of tissues and/or cell types. For example, using standard protocols, cytoplasmic and/or nuclear/membrane extracts may be prepared from HeLa S3 cells following seven minutes induction with 30 ng/mL TNF $\alpha$ . The extracts may then be

subjected to a series of chromatographic steps that includes Q Sepharose, gel filtration (HiLoad 16/60 Superdex 200), Mono Q, Phenyl Superose, gel filtration (Superdex 200 10/30) and Mono Q. This representative purification procedure is illustrated in Figure 2, and results in highly enriched IKK signalsome (compare, for example, Figures 5A and 5 6A).

An alternative purification procedure employs a two-step affinity method, based on recognition of IKK signalsome by the MKP-1 antibody (Figure 11A). Whole cell lysates from TNF $\alpha$ -stimulated HeLa cells may be immunoprecipitated with an anti-MKP-1 antibody. The IKK signalsome may be eluted with the specific MKP-1 peptide to 10 which the antibody was generated and fractionated further on a Mono Q column.

Throughout the fractionation, an *in vitro* kinase assay may be used to monitor the I $\kappa$ B kinase activity of the IKK signalsome. In such an assay, the ability of a fraction to phosphorylate an appropriate substrate (such as I $\kappa$ B $\alpha$  (SEQ ID NO:1) or a derivative or variant thereof) is evaluated by any of a variety of means that will be 15 apparent to those of ordinary skill in the art. For example, a substrate may be combined with a chromatographic fraction in a protein kinase buffer containing  $^{32}$ P  $\gamma$ -ATP, phosphatase inhibitors and protease inhibitors. The mixture may be incubated for 30 minutes at 30°C. The reaction may then be stopped by the addition of SDS sample buffer and analyzed using SDS-PAGE with subsequent autoradiography. Suitable substrates 20 include full length I $\kappa$ B $\alpha$  (SEQ ID NO:1), polypeptides comprising the N-terminal 54 amino acids of I $\kappa$ B $\alpha$ , full length I $\kappa$ B $\beta$  (SEQ ID NO:2) and polypeptides comprising the N-terminal 44 amino acids of I $\kappa$ B $\beta$ . Any of these substrates may be used with or without an N-terminal tag. One suitable substrate is a protein containing residues 1-54 of I $\kappa$ B $\alpha$  and an N-terminal GST tag (referred to herein as GST-I $\kappa$ B $\alpha$  1-54; SEQ ID NO:3). To 25 evaluate the specificity of an I $\kappa$ B kinase complex, I $\kappa$ B $\alpha$  mutants containing threonine or alanine residues at positions 32 and 36, and/or other modifications, may be employed.

Alternatively, an IKK signalsome may be prepared from its components which are also encompassed by the present invention. Such components may be produced using well known recombinant techniques, as described in greater detail below. 30 Components of an IKK signalsome may be native, or may be variants of a native component (*i.e.*, a component sequence may differ from the native sequence in one or

more substitutions and/or modifications, provided that the ability of a complex comprising the component variant to specifically phosphorylate I $\kappa$ B $\alpha$  is not substantially diminished). Substitutions and/or modifications may generally be made in non-critical and/or critical regions of the native protein. Variants may generally comprise residues of

5 L-amino acids, D-amino acids, or any combination thereof. Amino acids may be naturally-occurring or may be non-natural, provided that at least one amino group and at least one carboxyl group are present in the molecule;  $\alpha$ - and  $\beta$ -amino acids are generally preferred. A variant may also contain one or more rare amino acids (such as 4-hydroxyproline or hydroxylysine), organic acids or amides and/or derivatives of common

10 amino acids, such as amino acids having the C-terminal carboxylate esterified (*e.g.*, benzyl, methyl or ethyl ester) or amidated and/or having modifications of the N-terminal amino group (*e.g.*, acetylation or alkoxycarbonylation), with or without any of a wide variety of side-chain modifications and/or substitutions (*e.g.*, methylation, benzylation, *t*-butylation, tosylation, alkoxycarbonylation, and the like). Component variants may also,

15 or alternatively, contain other modifications, including the deletion or addition of amino acids that have minimal influence on the activity of the polypeptide. In particular, variants may contain additional amino acid sequences at the amino and/or carboxy termini. Such sequences may be used, for example, to facilitate purification or detection of the component polypeptide. In general, the effect of one or more substitutions and/or

20 modifications may be evaluated using the representative assays provided herein.

A component may generally be prepared from a DNA sequence that encodes the component using well known recombinant methods. DNA sequences encoding components of an IKK signalsome may be isolated by, for example, screening a suitable expression library (*i.e.*, a library prepared from a cell line or tissue that expresses

25 IKK signalsome, such as spleen, leukocytes, HeLa cells or Jurkat cells) with antibodies raised against IKK signalsome or against one or more components thereof. Protein components may then be prepared by expression of the identified DNA sequences, using well known recombinant techniques.

Alternatively, partial sequences of the components may be obtained using

30 standard biochemical purification and microsequencing techniques. For example, purified complex as described above may be run on an SDS-PAGE gel and individual

bands may be isolated and subjected to protein microsequencing. DNA sequences encoding components may then be prepared by amplification from a suitable human cDNA library, using polymerase chain reaction (PCR) and methods well known to those of ordinary skill in the art. For example, an adapter-ligated cDNA library prepared from a cell line or tissue that expresses IKK signalsome (such as HeLa or Jurkat cells) may be screened using a degenerate 5' specific forward primer and an adapter-specific primer. Degenerate oligonucleotides may also be used to screen a cDNA library, using methods well known to those of ordinary skill in the art. In addition, known proteins may be identified via Western blot analysis using specific antibodies.

Components of an IKK signalsome may also be identified by performing any of a variety of protein-protein interaction assays known to those of ordinary skill in the art. For example, a known component can be used as "bait" in standard two-hybrid screens to identify other regulatory molecules, which may include IKK-1, IKK-2, NF $\kappa$ B1, RelA, I $\kappa$ B $\beta$  and/or p70 S6 kinase (Kieran et al., *Cell* 62:1007-1018, 1990; Nolan et al., *Cell* 64:961-69, 1991; Thompson et al., *Cell* 80:573-82, 1995; Grove et al., *Mol. Cell Biol.* 11:5541-50, 1991).

Particularly preferred components of IKK signalsome are I $\kappa$ B kinases. An I $\kappa$ B kinase may be identified based upon its ability to phosphorylate one or more I $\kappa$ B proteins, which may be readily determined using the representative kinase assays described herein. In general, an I $\kappa$ B kinase is incorporated into an IKK signalsome, as described herein, prior to performing such assays, since an I $\kappa$ B kinase that is not complex-associated may not display the same phosphorylation activity as complex-associated I $\kappa$ B kinase. As noted above, an I $\kappa$ B kinase within an IKK signalsome specifically phosphorylates I $\kappa$ B $\alpha$  at residues S32 and S36, and phosphorylates I $\kappa$ B $\beta$  at residues 19 and 23, in response to specific stimuli.

As noted above, IKK-1 and IKK-2 are particularly preferred I $\kappa$ B kinases. IKK-1 and IKK-2 may be prepared by pooling the fractions from the Mono Q column containing peak I $\kappa$ B kinase activity and subjecting the pooled fractions to preparative SDS gel electrophoresis. The intensity of two prominent protein bands of ~85 and ~87 kDa (indicated by silver stain in Figure 11B as IKK-1 and IKK-2 respectively) correlates with the profile of I $\kappa$ B kinase activity. The ~85 kDa band, corresponding to IKK-1, has

been identified, within the context of the present invention, as CHUK (conserved helix-loop-helix ubiquitous kinase; *see* Connely and Marcu, *Cell. Mol. Biol. Res.* 41:537-49, 1995). The ~87 kDa band contains IKK-2.

Sequence analysis reveals that IKK-1 and IKK-2 are related protein serine  
5 kinases (51% identity) containing protein interaction motifs (Figure 13A). Both IKK-1 and IKK-2 contain the kinase domain at the N-terminus, and a leucine zipper motif and a helix-loop-helix motif in their C-terminal regions. Northern analysis indicates that mRNAs encoding IKK-2 are widely distributed in human tissues, with transcript sizes of ~4.5 kb and 6 kb (Figure 13B). The sequences of IKK-1 and IKK-2 are also provided as  
10 SEQ ID NOs: 7 and 8, respectively.

It has been found, within the context of the present invention, that rabbit reticulocyte lysate immunoprecipitates that contain IKK-1 or IKK-2 phosphorylate I $\kappa$ B $\alpha$  and I $\kappa$ B $\beta$  with the correct substrate specificity (*see* Figure 14A). Altered versions of these kinases interfere with translocation of RelA to the nucleus of TNF $\alpha$ -stimulated  
15 HeLa cells. Accordingly, IKK-1 and IKK-2 appear to control a significant early step of NF $\kappa$ B activation.

Other components of an IKK signalsome are also contemplated by the present invention. Such components may include, but are not limited to, upstream kinases such as MEKK-1 (Lee et al., *Cell* 88:213-22, 1997; Hirano et al., *J. Biol. Chem.*  
20 271:13234-38, 1996) or NIK (Malinin et al., *Nature* 385:540-44, 1997); adapter proteins that mediate an IKK-1:IKK-2 interaction; a component that crossreacts with anti-MKP-1; an inducible RelA kinase; and/or the E3 ubiquitin ligase that transfers multiubiquitin chains to phosphorylated I $\kappa$ B (Hershko and Ciechanover, *Annu. Rev. Biochem.* 61:761-807, 1992).

25 A component of an IKK signalsome may generally be prepared from DNA encoding the component by expression of the DNA in cultured host cells, which may be stable cell lines or transiently transfected cells. Preferably, the host cells are bacteria, yeast, baculovirus-infected insect cells or mammalian cells. The recombinant DNA may be cloned into any expression vector suitable for use within the host cell, using  
30 techniques well known to those of ordinary skill in the art. An expression vector may, but need not, include DNA encoding an epitope, such that the recombinant protein

contains the epitope at the N- or C-terminus. Epitopes such as glutathione-S transferase protein (GST), HA (hemagglutinin)-tag, FLAG and Histidine-tag may be added using techniques well known to those of ordinary skill in the art.

The DNA sequences expressed in this manner may encode native  
5 components of an IKK signalsome, or may encode portions or variants of native components, as described above. DNA molecules encoding variants may generally be prepared using standard mutagenesis techniques, such as oligonucleotide-directed site-specific mutagenesis. Sections of the DNA sequence may also, or alternatively, be removed to permit preparation of truncated polypeptides and DNA encoding additional  
10 sequences such as "tags" may be added to the 5' or 3' end of the DNA molecule.

IKK signalsome components may generally be used to reconstitute IKK signalsome. Such reconstitution may be achieved *in vitro* by combining IKK signalsome components in a suitable buffer. Alternatively, reconstitution may be achieved *in vivo* by expressing components in a suitable host cell, such as HeLa or HUVEC, as described  
15 herein.

Expressed IKK signalsome, or a component thereof, may be isolated in substantially pure form. Preferably, IKK signalsome or a component is isolated to a purity of at least 80% by weight, more preferably to a purity of at least 95% by weight, and most preferably to a purity of at least 99% by weight. In general, such purification  
20 may be achieved using, for example, the representative purification methods described herein or the standard techniques of ammonium sulfate fractionation, SDS-PAGE electrophoresis, and affinity chromatography. IKK signalsome and components for use in the methods of the present invention may be native, purified or recombinant.

In one aspect of the present invention, an IKK signalsome and/or one or  
25 more components thereof may be used to identify modulating agents, which may be antibodies (*e.g.*, monoclonal), polynucleotides or other drugs, that inhibit or stimulate signal transduction via the NF- $\kappa$ B cascade. Modulation includes the suppression or enhancement of NF- $\kappa$ B activity. Modulation may also include suppression or enhancement of I $\kappa$ B phosphorylation or the stimulation or inhibition of the ability of  
30 activated (*i.e.*, phosphorylated) IKK signalsome to phosphorylate a substrate. Compositions that inhibit NF- $\kappa$ B activity by inhibiting I $\kappa$ B phosphorylation may include

one or more agents that inhibit or block I $\kappa$ B $\alpha$  kinase activity, such as an antibody that neutralizes IKK signalsome, a competing peptide that represents the substrate binding domain of I $\kappa$ B kinase or a phosphorylation motif of I $\kappa$ B, an antisense polynucleotide or ribozyme that interferes with transcription and/or translation of I $\kappa$ B kinase, a molecule  
5 that inactivates IKK signalsome by binding to the complex, a molecule that binds to I $\kappa$ B and prevents phosphorylation by IKK signalsome or a molecule that prevents transfer of phosphate groups from the kinase to the substrate. Within certain embodiments, a modulating agent inhibits or enhances the expression or activity of IKK-1 and/or IKK-2.

In general, modulating agents may be identified by combining a test  
10 compound with an IKK signalsome, I $\kappa$ B kinase or a polynucleotide encoding an I $\kappa$ B kinase *in vitro* or *in vivo*, and evaluating the effect of the test compound on the I $\kappa$ B kinase activity using, for example, a representative assay described herein. An increase or decrease in kinase activity can be measured by adding a radioactive compound, such as  $^{32}$ P-ATP and observing radioactive incorporation into a suitable substrate for IKK  
15 signalsome, thereby determining whether the compound inhibits or stimulates kinase activity. Briefly, a candidate agent may be included in a reaction mixture containing compounds necessary for the kinase reaction (as described herein) and I $\kappa$ B substrate, along with IKK signalsome, I $\kappa$ B kinase or a polynucleotide encoding an I $\kappa$ B kinase. In general, a suitable amount of antibody or other agent for use in such an assay ranges from  
20 about 0.01  $\mu$ M to about 10  $\mu$ M. The effect of the agent on I $\kappa$ B kinase activity may then be evaluated by quantitating the incorporation of [ $^{32}$ P]phosphate into an I $\kappa$ B such as I $\kappa$ B $\alpha$  (or a derivative or variant thereof), and comparing the level of incorporation with that achieved using I $\kappa$ B kinase without the addition of a candidate agent. Alternatively, the effect of a candidate modulating agent on transcription of an I $\kappa$ B kinase may be  
25 measured, for example, by Northern blot analysis or a promoter/reporter-based whole cell assay.

Alternatively, for assays in which the test compound is combined with an IKK signalsome, the effect on a different IKK signalsome activity may be assayed. For example, an IKK signalsome also displays p65 kinase activity and IKK phosphatase  
30 activity. Assays to evaluate the effect of a test compound on such activities may be performed using well known techniques. For example, assays for p65 kinase activity may



generally be performed as described by Zhong et al., *Cell* 89:413-24, 1997. For phosphatase activity, an assay may generally be performed as described by Sullivan et al., *J. Biomolecular Screening* 2:19-24, 1997, using a recombinant phosphorylated I $\kappa$ B kinase as a substrate.

5 In another aspect of the present invention, IKK signalsome or I $\kappa$ B kinase may be used for phosphorylating an I $\kappa$ B such as I $\kappa$ B $\alpha$  (or a derivative or variant thereof) so as to render it a target for ubiquitination and subsequent degradation. I $\kappa$ B may be phosphorylated *in vitro* by incubating IKK signalsome or I $\kappa$ B kinase with I $\kappa$ B in a suitable buffer for 30 minutes at 30°C. In general, about 0.01  $\mu$ g to about 9  $\mu$ g of I $\kappa$ B  
10 kinase complex is sufficient to phosphorylate from about 0.5  $\mu$ g to about 2  $\mu$ g of I $\kappa$ B. Phosphorylated substrate may then be purified by binding to GSH-sepharose and washing. The extent of substrate phosphorylation may generally be monitored by adding [ $\gamma$ -<sup>32</sup>P]ATP to a test aliquot, and evaluating the level of substrate phosphorylation as described herein.

15 An IKK signalsome, component thereof, modulating agent and/or polynucleotide encoding a component and/or modulating agent may also be used to modulate NF- $\kappa$ B activity in a patient. Such modulation may occur by any of a variety of mechanisms including, but not limited to, direct inhibition or enhancement of I $\kappa$ B phosphorylation using a component or modulating agent; or inhibiting upstream  
20 activators, such as NIK or MEK, with IKK signalsome or a component thereof. As used herein, a "patient" may be any mammal, including a human, and may be afflicted with a disease associated with I $\kappa$ B kinase activation and the NF- $\kappa$ B cascade, or may be free of detectable disease. Accordingly, the treatment may be of an existing disease or may be prophylactic. Diseases associated with the NF- $\kappa$ B cascade include inflammatory  
25 diseases, neurodegenerative diseases, autoimmune diseases, cancer and viral infection.

Treatment may include administration of an IKK signalsome, a component thereof and/or an agent which modulates I $\kappa$ B kinase activity. For administration to a patient, one or more such compounds are generally formulated as a pharmaceutical composition. A pharmaceutical composition may be a sterile aqueous or non-aqueous  
30 solution, suspension or emulsion, which additionally comprises a physiologically acceptable carrier (*i.e.*, a non-toxic material that does not interfere with the activity of the

active ingredient). Any suitable carrier known to those of ordinary skill in the art may be employed in the pharmaceutical compositions of the present invention. Representative carriers include physiological saline solutions, gelatin, water, alcohols, natural or synthetic oils, saccharide solutions, glycols, injectable organic esters such as ethyl oleate  
5 or a combination of such materials. Optionally, a pharmaceutical composition may additionally contain preservatives and/or other additives such as, for example, antimicrobial agents, anti-oxidants, chelating agents and/or inert gases, and/or other active ingredients.

Alternatively, a pharmaceutical composition may comprise a  
10 polynucleotide encoding a component of an IKK signalsome and/or a modulating agent (such that the component and/or modulating agent is generated *in situ*) in combination with a physiologically acceptable carrier. In such pharmaceutical compositions, the polynucleotide may be present within any of a variety of delivery systems known to those of ordinary skill in the art, including nucleic acid, bacterial and viral expression systems,  
15 as well as colloidal dispersion systems, including liposomes. Appropriate nucleic acid expression systems contain the necessary polynucleotide sequences for expression in the patient (such as a suitable promoter and terminating signal). DNA may also be "naked," as described, for example, in Ulmer et al., *Science* 259:1745-49, 1993.

Various viral vectors that can be used to introduce a nucleic acid sequence  
20 into the targeted patient's cells include, but are not limited to, vaccinia or other pox virus, herpes virus, retrovirus, or adenovirus. Techniques for incorporating DNA into such vectors are well known to those of ordinary skill in the art. Preferably, the retroviral vector is a derivative of a murine or avian retrovirus including, but not limited to, Moloney murine leukemia virus (MoMuLV), Harvey murine sarcoma virus (HaMuSV),  
25 murine mammary tumor virus (MuMTV), and Rous Sarcoma Virus (RSV). A retroviral vector may additionally transfer or incorporate a gene for a selectable marker (to aid in the identification or selection of transduced cells) and/or a gene that encodes the ligand for a receptor on a specific target cell (to render the vector target specific). For example, retroviral vectors can be made target specific by inserting a nucleotide sequence encoding  
30 a sugar, a glycolipid, or a protein. Targeting may also be accomplished using an antibody, by methods known to those of ordinary skill in the art.

Viral vectors are typically non-pathogenic (defective), replication competent viruses, which require assistance in order to produce infectious vector particles. This assistance can be provided, for example, by using helper cell lines that contain plasmids that encode all of the structural genes of the retrovirus under the control of regulatory sequences within the LTR, but that are missing a nucleotide sequence which enables the packaging mechanism to recognize an RNA transcript for encapsulation. Such helper cell lines include (but are not limited to) Ψ2, PA317 and PA12. A retroviral vector introduced into such cells can be packaged and vector virion produced. The vector virions produced by this method can then be used to infect a tissue cell line, such as NIH 3T3 cells, to produce large quantities of chimeric retroviral virions.

Another targeted delivery system for polynucleotides is a colloidal dispersion system. Colloidal dispersion systems include macromolecule complexes, nanocapsules, microspheres, beads, and lipid-based systems including oil-in-water emulsions, micelles, mixed micelles, and liposomes. A preferred colloidal system for use as a delivery vehicle *in vitro* and *in vivo* is a liposome (*i.e.*, an artificial membrane vesicle). It has been shown that large unilamellar vesicles (LUV), which range in size from 0.2-4.0  $\mu\text{m}$  can encapsulate a substantial percentage of an aqueous buffer containing large macromolecules. RNA, DNA and intact virions can be encapsulated within the aqueous interior and be delivered to cells in a biologically active form (Fraley, et al., *Trends Biochem. Sci.* 6:77, 1981). In addition to mammalian cells, liposomes have been used for delivery of polynucleotides in plant, yeast and bacterial cells. In order for a liposome to be an efficient gene transfer vehicle, the following characteristics should be present: (1) encapsulation of the genes of interest at high efficiency while not compromising their biological activity; (2) preferential and substantial binding to a target cell in comparison to non-target cells; (3) delivery of the aqueous contents of the vesicle to the target cell cytoplasm at high efficiency; and (4) accurate and effective expression of genetic information (Mannino, et al., *Biotechniques* 6:882, 1988).

The targeting of liposomes can be classified based on anatomical and mechanistic factors. Anatomical classification is based on the level of selectivity and may be, for example, organ-specific, cell-specific, and/or organelle-specific. Mechanistic targeting can be distinguished based upon whether it is passive or active. Passive

targeting utilizes the natural tendency of liposomes to distribute to cells of the reticuloendothelial system (RES) in organs which contain sinusoidal capillaries. Active targeting, on the other hand, involves alteration of the liposome by coupling the liposome to a specific ligand such as a monoclonal antibody, sugar, glycolipid, or protein, or by  
5 changing the composition or size of the liposome in order to achieve targeting to organs and cell types other than the naturally occurring sites of localization.

Routes and frequency of administration, as well doses, will vary from patient to patient. In general, the pharmaceutical compositions may be administered intravenously, intraperitoneally, intramuscularly, subcutaneously, intracavity or  
10 transdermally. Between 1 and 6 doses may be administered daily. A suitable dose is an amount that is sufficient to show improvement in the symptoms of a patient afflicted with a disease associated with the NF- $\kappa$ B cascade. Such improvement may be detected by monitoring inflammatory responses (*e.g.*, edema, transplant rejection, hypersensitivity) or through an improvement in clinical symptoms associated with the disease. The dosage  
15 may generally vary depending on the nature of the modulating agent and the disease to be treated. Typically, the amount of modulating agent present in a dose, or produced *in situ* by DNA present in a dose, ranges from about 1  $\mu$ g to about 200 mg per kg of host. Suitable dose sizes will vary with the size of the patient, but will typically range from about 10 mL to about 500 mL for 10-60 kg animal.

20 In another aspect, the present invention provides methods for detecting the level of stimulus-inducible I $\kappa$ B kinase activity in a sample. The level of I $\kappa$ B kinase activity may generally be determined via an immunokinase assay, in which IKK signalsome is first immunoprecipitated with an antibody that binds to the complex. The immunoprecipitated material is then subjected to a kinase assay as described herein.  
25 Substrate specificity may be further evaluated as described herein to distinguish the activity of a stimulus-inducible I $\kappa$ B kinase complex from other kinase activities.

The present invention also provides methods for detecting the level of IKK signalsome, or a component thereof, in a sample. The amount of IKK signalsome, I $\kappa$ B kinase or nucleic acid encoding I $\kappa$ B kinase, may generally be determined using a reagent  
30 that binds to I $\kappa$ B kinase, or to DNA or RNA encoding a component thereof. To detect nucleic acid encoding a component, standard hybridization and/or PCR techniques may

be employed using a nucleic acid probe or a PCR primer. Suitable probes and primers may be designed by those of ordinary skill in the art based on the component sequence. To detect IKK signalsome or a component thereof, the reagent is typically an antibody, which may be prepared as described below.

5           There are a variety of assay formats known to those of ordinary skill in the art for using an antibody to detect a protein in a sample. *See, e.g., Harlow and Lane, Antibodies: A Laboratory Manual*, Cold Spring Harbor Laboratory, 1988. For example, the antibody may be immobilized on a solid support such that it can bind to and remove the protein from the sample. The bound protein may then be detected using a second  
10 antibody that binds to the antibody/protein complex and contains a detectable reporter group. Alternatively, a competitive assay may be utilized, in which protein that binds to the immobilized antibody is labeled with a reporter group and allowed to bind to the immobilized antibody after incubation of the antibody with the sample. The extent to which components of the sample inhibit the binding of the labeled protein to the antibody  
15 is indicative of the level of protein within the sample. Suitable reporter groups for use in these methods include, but are not limited to, enzymes (*e.g.*, horseradish peroxidase), substrates, cofactors, inhibitors, dyes, radionuclides, luminescent groups, fluorescent groups and biotin.

Antibodies encompassed by the present invention may be polyclonal or  
20 monoclonal, and may bind to IKK signalsome and/or one or more components thereof (*e.g.*, IKK-1 and/or IKK-2). Preferred antibodies are those antibodies that inhibit or block I $\kappa$ B kinase activity *in vivo* and within an *in vitro* assay, as described above. Other preferred antibodies are those that bind to one or more I $\kappa$ B proteins. As noted above, antibodies and other agents having a desired effect on I $\kappa$ B kinase activity may be  
25 administered to a patient (either prophylactically or for treatment of an existing disease) to modulate the phosphorylation of an I $\kappa$ B, such as I $\kappa$ B $\alpha$ , *in vivo*.

Antibodies may be prepared by any of a variety of techniques known to those of ordinary skill in the art (*see, e.g., Harlow and Lane, Antibodies: A Laboratory Manual*, Cold Spring Harbor Laboratory, 1988). In one such technique, an immunogen  
30 comprising the protein of interest is initially injected into a suitable animal (*e.g.*, mice, rats, rabbits, sheep and goats), preferably according to a predetermined schedule

incorporating one or more booster immunizations, and the animals are bled periodically. Polyclonal antibodies specific for the protein may then be purified from such antisera by, for example, affinity chromatography using the protein coupled to a suitable solid support.

5            Monoclonal antibodies specific for an IKK signalsome or a component thereof may be prepared, for example, using the technique of Kohler and Milstein, *Eur. J. Immunol.* 6:511-519, 1976, and improvements thereto. Briefly, these methods involve the preparation of immortal cell lines capable of producing antibodies having the desired specificity (i.e., reactivity with the complex and/or component of interest). Such cell  
10 lines may be produced, for example, from spleen cells obtained from an animal immunized as described above. The spleen cells are then immortalized by, for example, fusion with a myeloma cell fusion partner, preferably one that is syngenic with the immunized animal. For example, the spleen cells and myeloma cells may be combined with a nonionic detergent for a few minutes and then plated at low density on a selective  
15 medium that supports the growth of hybrid cells, but not myeloma cells. A preferred selection technique uses HAT (hypoxanthine, aminopterin, thymidine) selection. After a sufficient time, usually about 1 to 2 weeks, colonies of hybrids are observed. Single colonies are selected and tested for binding activity against the polypeptide. Hybridomas having high reactivity and specificity are preferred.

20            Monoclonal antibodies may be isolated from the supernatants of growing hybridoma colonies. In addition, various techniques may be employed to enhance the yield, such as injection of the hybridoma cell line into the peritoneal cavity of a suitable vertebrate host, such as a mouse. Monoclonal antibodies may then be harvested from the ascites fluid or the blood. Contaminants may be removed from the antibodies by  
25 conventional techniques, such as chromatography, gel filtration, precipitation, and extraction.

          In a related aspect of the present invention, kits for detecting the level of IKK signalsome, I $\kappa$ B kinase, nucleic acid encoding I $\kappa$ B kinase and/or I $\kappa$ B kinase activity in a sample are provided. Any of a variety of samples may be used in such assays,  
30 including eukaryotic cells, bacteria, viruses, extracts prepared from such organisms and fluids found within living organisms. In general, the kits of the present invention

comprise one or more containers enclosing elements, such as reagents or buffers, to be used in the assay.

A kit for detecting the level of IKK signalsome, I $\kappa$ B kinase or nucleic acid encoding I $\kappa$ B kinase typically contains a reagent that binds to the compound of interest.

- 5 To detect nucleic acid encoding I $\kappa$ B kinase, the reagent may be a nucleic acid probe or a PCR primer. To detect IKK signalsome or I $\kappa$ B kinase, the reagent is typically an antibody. Such kits also contain a reporter group suitable for direct or indirect detection of the reagent (*i.e.*, the reporter group may be covalently bound to the reagent or may be bound to a second molecule, such as Protein A, Protein G, immunoglobulin or lectin, which is itself capable of binding to the reagent). Suitable reporter groups include, but are not limited to, enzymes (*e.g.*, horseradish peroxidase), substrates, cofactors, inhibitors, dyes, radionuclides, luminescent groups, fluorescent groups and biotin. Such reporter groups may be used to directly or indirectly detect binding of the reagent to a sample component using standard methods known to those of ordinary skill in the art.

- 15 In yet another aspect, IKK signalsome may be used to identify one or more native upstream kinases (*i.e.*, kinases that phosphorylate and activate IKK signalsome *in vivo*) or other regulatory molecules that affect I $\kappa$ B kinase activity (such as phosphatases or molecules involved in ubiquitination), using methods well known to those of ordinary skill in the art. For example, IKK signalsome components may be used in a yeast two-  
20 hybrid system to identify proteins that interact with such components. Alternatively, an expression library may be screened for cDNAs that phosphorylate IKK signalsome or a component thereof.

The following Examples are offered by way of illustration and not by way of limitation.

## EXAMPLES

Example 15        Recruitment of NF $\kappa$ B into IKK Signosome during Activation

This example illustrates the recruitment of NF $\kappa$ B into a protein complex (the IKK signosome) containing I $\kappa$ B kinase and other signaling proteins.

Cytoplasmic extracts of either unstimulated or stimulated Jurkat cells were fractionated on a Superdex 200 gel filtration column, and I $\kappa$ B $\alpha$  was visualized by  
10 immunoblot analysis. Jurkat cells were grown to a cell density of  $1.5 \times 10^6$  cells/ml and either not stimulated or induced for 10 minutes with PMA (50 ng/ml)/PHA (1  $\mu$ g/ml). Cells were harvested and resuspended in two volumes HLB buffer (20 mM Tris pH 8.0, 2 mM EDTA, 1 mM EGTA, 10 mM  $\beta$ -glycerophosphate, 10 mM NaF, 10 mM PNPP, 300  $\mu$ M Na<sub>3</sub>VO<sub>4</sub>, 1 mM benzamidine, 2 mM PMSF, 10  $\mu$ g/ml aprotinin, 1  $\mu$ g/ml leupeptin, 1  
15  $\mu$ g/ml pepstatin, 1 mM DTT), made 0.1% NP40 and left on ice for 15 minutes, and lysed with a glass Dounce homogenizer. The nuclei were pelleted at 10,000 rpm for 20 minutes in a Sorval SS34 rotor. The supernatant was further centrifuged at 40,000 rpm for 60 min in a Ti50.1 rotor. All procedures were carried out at 4°C. The S-100 fraction was concentrated and chromatographed on Hi Load 16/60 Superdex 200 prep grade gel  
20 filtration column that was equilibrated in GF buffer (20 mM Tris HCl pH 8.0, 150 mM NaCl, 1 mM EDTA, 1 mM EGTA, 5% glycerol, 0.025% Brij 35, 1 mM benzamidine, 2 mM PMSF, 10 mM  $\beta$ -glycerophosphate, 10 mM NaF, 10 mM PNPP, 300  $\mu$ M Na<sub>3</sub>VO<sub>4</sub>, 10  $\mu$ g/ml aprotinin, 1  $\mu$ g/ml leupeptin, 1  $\mu$ g/ml pepstatin, 1 mM DTT). Isolated fractions were analyzed by western blot analysis using either anti-I $\kappa$ B $\alpha$  or anti-JNK antibodies  
25 (Santa Cruz, Inc., Santa Cruz, CA).

As shown in Figure 1A, I $\kappa$ B $\alpha$  in cell extracts from unstimulated cells eluted with an apparent molecular weight of ~300 kDa (lanes 5-7), consistent with the chromatographic properties of the inactive NF $\kappa$ B-I $\kappa$ B complex (Baeuerle and Baltimore, *Genes Dev.* 3:1689-98, 1989). In contrast, phosphorylated I $\kappa$ B $\alpha$  (from cells stimulated  
30 for periods too short to permit complete degradation of the protein) migrated at ~600 kDa on the same chromatography columns (lanes 2, 3). This difference in migration was



specific for I $\kappa$ B, since analysis of the same fractions indicated that the Jun N-terminal kinases JNK1 and JNK2 migrated with low apparent molecular weight and showed no difference in chromatographic behavior between stimulated and unstimulated cells. Stimulation-dependent recruitment of I $\kappa$ B into this larger protein complex corresponded  
5 with the appearance of phosphorylated I $\kappa$ B, suggesting that the complex contained the specific I $\kappa$ B kinases that mediate I $\kappa$ B phosphorylation. These results demonstrate that that NF $\kappa$ B activation involves recruitment into a protein complex (the IKK signalsome) containing I $\kappa$ B kinase and other signaling proteins.

10

### Example 2

#### Partial Purification of IKK Signalsome and Identification of Co-purifying Components

This Example illustrates the fractionation of extracts containing I $\kappa$ B kinase. Whole cell extracts from TNF $\alpha$ -stimulated cells were fractionated by gel  
15 filtration, ion exchange, and other chromatographic methods, as described above. I $\kappa$ B kinase activity in the fractions was assayed by phosphorylation of GST-I $\kappa$ B $\alpha$  (1-54) (SEQ ID NO:3) or GST-I $\kappa$ B $\beta$  (1-44) (SEQ ID NO:4). Kinase assays were performed in 20 mM HEPES pH 7.7, 2 mM MgCl<sub>2</sub>, 2 mM MnCl<sub>2</sub>, 10  $\mu$ M ATP, 1-3  $\mu$ Ci  $\gamma$ -[<sup>32</sup>P]-ATP, 10 mM  $\beta$ -glycerophosphate, 10 mM NaF, 10 mM PNPP, 300  $\mu$ M Na<sub>3</sub>VO<sub>4</sub>, 1 mM benzamidine, 2  
20  $\mu$ M PMSF, 10  $\mu$ g/ml aprotinin, 1  $\mu$ g/ml leupeptin, 1  $\mu$ g/ml pepstatin, 1 mM DTT) at 30°C for 30 to 60 minutes in the presence of the indicated substrate. The kinase reaction was stopped by the addition of 6X SDS-PAGE sample buffer, subjected to SDS-PAGE analysis and visualized using autoradiography. GST-I $\kappa$ B substrates for use in the above assay were prepared using standard techniques for bacterially expressed GST-protein (*see*  
25 *Current Protocols in Molecular Biology* 2:16.7.1-16.7.7, 1996). Bacterial cells were lysed, GST-proteins were purified via binding to GST-agarose beads, washed several times, eluted from the beads with glutathione, dialyzed against kinase assay buffer and stored at -80°C. The specificity of the kinase was established by using mutant GST-I $\kappa$ B $\alpha$  (1-54) in which serines 32, 36 had been mutated to threonine (SEQ ID NO:5), and GST-  
30 I $\kappa$ B $\beta$  (1-44) in which serines 19, 23 had been mutated to alanine (SEQ ID NO:6).

I $\kappa$ B kinase activity was not observed in extracts from unstimulated cells, while stimulation with TNF $\alpha$  for 5-7 minutes resulted in strong induction of kinase activity. As shown in Figure 1B, the I $\kappa$ B kinase activity from stimulated cells chromatographed on gel filtration as a broad peak of ~500-700 kDa, consistent with its  
5 presence in a large protein complex potentially containing other components required for NF $\kappa$ B activation.

NF $\kappa$ B activation is known to occur under conditions that also stimulate MAP kinase pathways (Lee et al., *Cell* 88:213-22, 1997; Hirano, et al., *J. Biol. Chem.* 271:13234-38, 1996). Accordingly, further experiments were performed to detect  
10 proteins associated with MAP kinase and phosphatase cascades at various stages of purification of the IKK signalsome. In addition to RelA and I $\kappa$ B $\beta$ , MEKK-1 and two tyrosine-phosphorylated proteins of ~55 and ~40 kDa copurified with I $\kappa$ B kinase activity (Figure 1C). Antibodies to Rel A and I $\kappa$ B $\beta$  were obtained from Santa Cruz  
Biotechnology, Inc. (Santa Cruz, CA), and antibodies to MEKK-1 were obtained from  
15 Upstate Biotechnology (Lake Placid, NY). Other signaling components, including PKC $\zeta$ , PP1 and PP2A, were detected in the same fractions as the I $\kappa$ B kinase in early chromatographic steps but did not copurify at later chromatographic steps (data not shown). Most interestingly, an unidentified protein of ~50 kDa, detected by its  
crossreaction with an antibody to MKP-1, copurified with I $\kappa$ B kinase through several  
20 purification steps (Figure 1C). This protein is unlikely to be MKP-1 itself, since the molecular weight of authentic MKP-1 is 38 kDa.

### Example 3

#### 25 Preparation of IKK Signalsome from HeLa S3 Cell Extracts

This Example illustrates an alternate preparation of an IKK signalsome, and the characterization of the complex.

HeLa S3 cells were grown to a cell density of approximately  $0.6 \times 10^6$ /mL, concentrated 10 fold and induced with TNF $\alpha$  (30 ng/mL) for seven minutes. Two  
30 volumes of ice-cold PBS containing phosphatase inhibitors (10 mM sodium fluoride, 0.3 mM sodium orthovanadate and 20 mM  $\beta$ -glycerophosphate) were then added. The cells

were spun down, washed once with ice-cold PBS containing phosphatase inhibitors and snap frozen.

Standard protocols were then used to prepare cytoplasmic and nuclear extracts. More specifically, the frozen HeLa S3 cell pellet was quick-thawed at 37°C, resuspended in 2 volumes of ice-cold Hypotonic Lysis Buffer (20mM Tris pH 8.0, 2mM EDTA, 1mM EGTA, 10mM  $\beta$ -glycerophosphate, 10mM NaF, 10mM PNPP, 0.3mM Na<sub>2</sub>VO<sub>4</sub>, 5mM sodium pyrophosphate, 1mM benzamidine, 2mM PMSF, 10 $\mu$ g/mL aprotinin, 1 $\mu$ g/mL leupeptin and 1 $\mu$ g/mL pepstatin), and left to incubate on ice for 30 min. The swollen cells were then dounced 30 times using a tight pestle and the nuclei were pelleted at 10,000 rpm for 15 minutes at 4°C. The supernatant was clarified via ultracentrifugation (50,000 rpm for 1 hour at 4°C) to generate the final cytoplasmic extract. The nuclear/membrane pellet was resuspended in an equal volume of High Salt Extraction Buffer (20mM Tris pH 8.0, 0.5M NaCl, 1mM EDTA, 1mM EGTA, 0.25% Triton X-100, 20mM  $\beta$ -glycerophosphate, 10mM NaF, 10mM PNPP, 0.3mM Na<sub>2</sub>VO<sub>4</sub>, 1mM benzamidine, 1mM PMSF, 1mM DTT, 10 $\mu$ g/mL aprotinin, 1 $\mu$ g/mL leupeptin and 1 $\mu$ g/mL pepstatin) and allowed to rotate at 4°C for 30 minutes. Cell debris was removed via centrifugation at 12,500 rpm for 30 minutes at 4°C and the resulting supernatant was saved as the nuclear/membrane extract.

These extracts were then independently subjected to a series of chromatographic steps (shown in Figure 2) using a Pharmacia FPLC system (Pharmacia Biotech, Piscataway, NJ):

(1) Q Sepharose (Pharmacia Biotech, Piscataway, NJ) - the column was run with a linear gradient starting with 0.0M NaCl Q Buffer (20mM Tris pH 8.0, 0.5mM EDTA, 0.5mM EGTA, 0.025% Brij 35, 20mM  $\beta$ -glycerophosphate, 10mM NaF, 0.3mM Na<sub>2</sub>VO<sub>4</sub>, 1mM benzamidine, 1mM PMSF, 2mM DTT, 10 $\mu$ g/mL aprotinin, 1 $\mu$ g/mL leupeptin and 1 $\mu$ g/mL pepstatin) and ending with 0.5M NaCl Q Buffer. The IkB $\alpha$  kinase activity eluted between 0.25 and 0.4 M NaCl.

(2) Gel Filtration HiLoad 16/60 Superdex 200) (Pharmacia Biotech, Piscataway, NJ) - the column was run with Gel Filtration Buffer (20mM Tris pH 8.0, 150mM NaCl, 1mM EDTA, 1mM EGTA, 0.05% Brij 35, 20mM  $\beta$ -glycerophosphate, 10mM NaF, 0.3mM Na<sub>2</sub>VO<sub>4</sub>, 1mM benzamidine, 1mM PMSF, 1mM

DTT, 10 $\mu$ g/mL aprotinin, 1 $\mu$ g/mL leupeptin and 1 $\mu$ g/mL pepstatin). The peak I $\kappa$ B $\alpha$  kinase activity eluted at 40-48 mL, which corresponds to a molecular weight of 731 kD to 623 kD.

(3) HR 5/5 Mono Q (Pharmacia Biotech, Piscataway, NJ) - the  
5 column was run with a linear gradient starting with 0.0M NaCl Q Buffer and ending with 0.5M NaCl Q Buffer (without Brij detergent to prepare sample for Phenyl Superose column). The I $\kappa$ B $\alpha$  kinase activity eluted between 0.25 and 0.4 M NaCl.

(4) HR Phenyl Superose (Pharmacia Biotech, Piscataway, NJ) -  
the column was run with a linear gradient of 1.0M to 0.0M ammonium sulfate in Phenyl  
10 Superose Buffer (20mM Tris pH 8.0, 0.25mM EDTA, 1mM EGTA, 20mM  $\beta$ -glycerophosphate, 10mM NaF, 0.1mM Na<sub>2</sub>VO<sub>4</sub>, 1mM benzamidine, 1mM PMSF, 1mM DTT, 10 $\mu$ g/mL aprotinin, 1 $\mu$ g/mL leupeptin and 1 $\mu$ g/mL pepstatin). The I $\kappa$ B $\alpha$  kinase activity eluted between 0.35 and 0.2 M ammonium sulfate.

(5) Gel Filtration Superdex 200 HR 10/30 (Pharmacia Biotech,  
15 Piscataway, NJ) - the column was run with Gel Filtration Buffer (see (2), above). The peak of activity eluted at 8-10 mL, which corresponds to a molecular weight of 720 kD to 600 kD.

(6) HR 5/5 Mono Q - the column was run as in (3) above except  
that the 0.05% Brij 35 was included in all Q buffers.  
20 I $\kappa$ B $\alpha$  kinase activity, with similar substrate specificity and molecular weight, was isolated from both the cytoplasmic and nuclear/membrane extracts.

At each step of the fractionation, I $\kappa$ B kinase activity was monitored using an *in vitro* assay. The assay was performed by combining 2  $\mu$ g of the respective I $\kappa$ B substrate (GST-I $\kappa$ B $\alpha$  1-54 (wildtype) or GST-I $\kappa$ B $\alpha$  (S32/36 to T), as described below)  
25 with 3-5  $\mu$ L chromatographic fraction and 20  $\mu$ L of Kinase Assay Buffer (20 mM HEPES pH 7.4, 10 mM MgCl<sub>2</sub>, 10 mM MnCl<sub>2</sub>, 20 mM NaCl, 1mM DTT, 20mM PNPP, 20 $\mu$ M ATP, 20mM  $\beta$ -glycerophosphate, 10mM NaF, 0.1mM Na<sub>2</sub>VO<sub>4</sub>, 1mM benzamidine, 1mM PMSF) containing  $\gamma$ <sup>32</sup>P-ATP, and incubating for 30 minutes at 30°C. The kinase reaction was terminated by adding 8  $\mu$ L of 6x SDS-PAGE sample buffer. The entire sample was  
30 run on a 12% polyacrylamide gel, dried and subjected to autoradiography.

I $\kappa$ B substrates for use in the above assay were prepared using standard techniques (*see* Haskill et al., *Cell* 65:1281-1289, 1991). The GST-I $\kappa$ B $\alpha$  1-54 (wildtype) or GST-I $\kappa$ B $\alpha$  (S32/36 to T) substrates were prepared using standard techniques for bacterially expressed GST-protein. Bacterial cells were lysed, GST proteins were  
5 purified via binding to GST-agarose beads, washed several times, eluted from the beads with glutathione, dialyzed against 50 mM NaCl Kinase Assay Buffer and stored at -80°C.

The TNF $\alpha$ -inducibility of I $\kappa$ B kinase activity was initially evaluated by Western blot analysis of the levels of I $\kappa$ B in HeLa S3 cytoplasmic extracts following gel filtration. I $\kappa$ B $\alpha$  was assayed by running 18  $\mu$ L of the gel filtration fractions on 10% SDS  
10 PAGE, transferring to Nitrocellulose Membrane (Hybond-ECL, Amersham Life Sciences, Arlington Height, IL) using standard blotting techniques and probing with anti-I $\kappa$ B $\alpha$  antibodies (Santa Cruz Biotechnology, Inc., Santa Cruz, CA). TNF $\alpha$ -inducibility was evaluated by comparing the level of I $\kappa$ B $\alpha$  in cells that were (Figure 3B) and were not (Figure 3A) exposed to TNF $\alpha$  (30 ng/mL for seven minutes, as described above).

15 The I $\kappa$ B kinase activity of these cytoplasmic extracts was evaluated using the kinase assay described above. As shown in Figure 4B, the extract of TNF $\alpha$ -treated cells phosphorylated GST-I $\kappa$ B $\alpha$  1-54 (wildtype), while the untreated cell extract showed significantly lower levels of I $\kappa$ B $\alpha$  kinase activity (Figure 4A).

Cytoplasmic extracts of TNF $\alpha$ -treated HeLa S3 cells (following Q  
20 Sepharose fractionation) were also subjected to *in vitro* kinase assays, using the N-terminal portion of I $\kappa$ B $\alpha$  (residues 1 to 54) as substrate. With the wild type substrate, phosphorylation of GST-I $\kappa$ B $\alpha$  1-54 was readily apparent (Figure 5A). In contrast, substrate containing threonine substitutions at positions 32 and 36 was not phosphorylated (Figure 5B).

25 Following chromatographic fractionation by Q Sepharose, Superdex 200, MonoQ-Sepharose and Phenyl Superose, *in vitro* kinase assay showed substantial purification of the I $\kappa$ B kinase activity (Figure 6A). Further purification of the I $\kappa$ B kinase was achieved by passing the sample over, in series, an analytical Superdex 200 and Mono Q HR 5/5, resulting in 8 major protein bands as determined by silver staining. As before,  
30 the use of substrate containing threonine substitutions at positions 32 and 36 markedly

reduced the phosphorylation (Figure 6B). These results demonstrate the purification of a stimulus-inducible I $\kappa$ B $\alpha$  kinase complex, which specifically phosphorylates serine residues at positions 32 and 36 of I $\kappa$ B $\alpha$  without the addition of exogenous factors.

5

#### Example 4

##### Immunoprecipitation of IKK Signalsome Using Anti MKP-1 Antibodies

This Example illustrates the immunoprecipitation of I $\kappa$ B kinase activity from cytoplasmic extracts prepared from stimulated cells.

10

##### A. Immunoprecipitation of I $\kappa$ B Kinase Complex from HeLa Cells

HeLa cells were TNF- $\alpha$ -treated (30  $\mu$ g/mL, 7 minutes) and fractionated by gel filtration as described in Example 3. Twenty  $\mu$ L of gel filtration fraction #6 (corresponding to about 700 kD molecular weight) and 1  $\mu$ g purified antibodies raised against MKP-1 (Santa Cruz Biotechnology, Inc., Santa Cruz, CA) were added to 400  $\mu$ L of ice cold 1x Pull Down Buffer (20mM Tris pH 8.0, 250 mM NaCl, 0.05% NP-40, 3mM EGTA, 5 mM EDTA, 10 mM  $\beta$ -glycerophosphate, 10 mM NaF, 10 mM PNPP, 300  $\mu$ M Na<sub>3</sub>VO<sub>4</sub>, 1 mM benzamidine, 2  $\mu$ M PMSF, 10  $\mu$ g/ml aprotinin, 1  $\mu$ g/ml leupeptin, 1  $\mu$ g/ml pepstatin, 1 mM DTT). The sample was gently rotated for 1 hour at 4°C, at which time 40 $\mu$ L of protein A-agarose beads (50:50 slurry, Santa Cruz Biotechnology, Inc., Santa Cruz, CA) was added. The sample was then rotated for an additional 1.5 hours at 4°C. The protein A-agarose beads were pelleted at 3,000 rpm for 2 minutes at 4°C and the pellet was washed three times with ice cold Pull Down Buffer (800  $\mu$ L per wash).

The pellet was subjected to the standard *in vitro* I $\kappa$ B $\alpha$  kinase assay (as described above) using either 2  $\mu$ g GST-I $\kappa$ B $\alpha$ 1-54 (wildtype) or 2  $\mu$ g GST-I $\kappa$ B $\alpha$ 1-54 (S32/36 to T) as the substrate.

The results, shown in Figure 7, demonstrate that antibodies directed against MKP-1 immunoprecipitate the stimulus-inducible I $\kappa$ B $\alpha$  kinase activity. The substrate specificity of this I $\kappa$ B $\alpha$  kinase activity corresponds to what has been described

*in vivo* (strong phosphorylation of the GST-I $\kappa$ B $\alpha$ 1-54 (wildtype) and no phosphorylation using GST-I $\kappa$ B $\alpha$ 1-54 (S32/36 to T).

#### B. Characterization of Immunoprecipitated IKK Signalsome

5 For these studies, small scale immunoprecipitation were performed using two 150 mm plates of HeLa cells (one stimulated and one unstimulated). Whole cell lysates were diluted 4-fold with 2x Pull-Down Buffer (40 mM Tris pH 8.0, 500 mM NaCl, 0.1% NP-40, 6 mM EDTA, 6 mM EGTA, 10 mM  $\beta$ -glycerophosphate, 10 mM NaF, 10 mM PNPP, 300  $\mu$ M Na<sub>3</sub>VO<sub>4</sub>, 1 mM benzamidine, 2  $\mu$ M PMSF, 10  $\mu$ g/ml  
10 aprotonin, 1  $\mu$ g/ml leupeptin, 1  $\mu$ g/ml pepstatin, 1 mM DTT) and 2-4  $\mu$ g of the indicated antibody was added. Lysates were incubated on ice for 1-2 hours, 10  $\mu$ l of Protein A or G beads were added, and lysates were left to incubate with gentle rotation for an additional 1 hour at 4°C. The immunoprecipitate was then washed 3 times with 2x Pull-Down Buffer, 1X with kinase buffer without ATP and subjected to a kinase assay as described  
15 in Example 2. There was no noticeable loss in I $\kappa$ B kinase activity when the immunoprecipitate was subjected to more rigorous washing, such as in RIPA buffer (20 mM Tris, 250 mM NaCl, 1% NP-40, 1% DOC, 0.1% SDS, 3mM EDTA, 3mM EGTA, 10 mM  $\beta$ -glycerophosphate, 10 mM NaF, 10 mM PNPP, 300  $\mu$ M Na<sub>3</sub>VO<sub>4</sub>, 1 mM benzamidine, 2  $\mu$ M PMSF, 10  $\mu$ g/ml aprotonin, 1  $\mu$ g/ml leupeptin, 1  $\mu$ g/ml pepstatin, 1  
20 mM DTT) or washes up to 3.5 M urea.

Of a large panel of antibodies tested, one of three anti-MKP-1 antibodies efficiently co-immunoprecipitated an inducible I $\kappa$ B kinase activity from HeLa cells as well as primary human umbilical vein endothelial cells (HUVEC). The co-immunoprecipitated kinase (IKK signalsome kinase) was inactive in unstimulated HeLa  
25 cells, but was rapidly activated within minutes of TNF $\alpha$  stimulation (Figure 8A, top panel). The IKK signalsome kinase did not phosphorylate a mutant GST-I $\kappa$ B $\alpha$  protein in which serine residues 32 and 36 had been mutated to threonine (Figure 8A top panel, even-numbered lanes). Activation of the signalsome kinase was maximal at 5 minutes and declined thereafter, a time course consistent with the time course of I $\kappa$ B $\alpha$  phosphorylation and degradation under the same conditions (Figure 8A, bottom panel).  
30 As expected, the signalsome I $\kappa$ B kinase was also activated by stimulation of cells with

IL-1 or PMA (Figure 8B, lanes 1-4); moreover, its activity was inhibited in cells treated with TPCK, a known inhibitor of NF $\kappa$ B activation (Figure 8B, lane 7). Additionally, the IKK signalsome kinase specifically phosphorylated full-length wild-type I $\kappa$ B $\alpha$ , but not a mutant I $\kappa$ B $\alpha$  bearing the serine 32, 36 to alanine mutations, in the context of a physiological RelA-I $\kappa$ B $\alpha$  complex (Figure 8C, lanes 3, 4). Together these results indicate that the anti-MKP-1 antibody co-immunoprecipitated the IKK signalsome. The signalsome-associated I $\kappa$ B kinase met all the criteria expected of the authentic I $\kappa$ B kinase and had no detectable I $\kappa$ B $\alpha$  C-terminal kinase activity.

The specificity of the IKK signalsome kinase was further established by kinetic analysis and by examining its activity on various peptides and recombinant protein substrates (Figure 9A). For these studies, synthetic peptides (Alpha Diagnostics International, San Antonio, TX) were prepared with the following sequences:

I $\kappa$ B $\alpha$ (21-41): CKKERLLDDRHDSGLDSMKDEE (SEQ ID NO:11)

I $\kappa$ B $\alpha$ (21-41) S/T mutant: CKKERLLDDRHDTGLDTMKDEE (SEQ ID NO:12)

c-Fos(222-241): DLTGGPEVAT(PO3)PESEEAFPLP (SEQ ID NO:13)

MKP-1: CPTNSALNYLKSPITTSPS (SEQ ID NO:14)

cJun(56-70): CNSDLLTSPDVGLLK (SEQ ID NO:15)

cJun(65-79): CVGLLKLASPELERL (SEQ ID NO:16)

Phosphorylation of these peptides (100  $\mu$ M) was performed using a kinase reaction as described above. Reactions were for one hour at room temperature and were terminated by the addition of SDS-PAGE loading buffer. SDS-PAGE with a 16% Tris/tricine gel (Novex, San Diego, CA) or a 4-20% Tris/glycine gel (Novex, San Diego, CA) was used to characterize the reaction products. Gels were washed, dried in vacuo, and exposed to autoradiographic film.

Inhibition of immunopurified IKK signalsome activity was measured by  $^{32}$ P incorporation into GST-I $\kappa$ B $\alpha$ (1-54) in a discontinuous assay using the reaction conditions described above. The concentrations of GST-I $\kappa$ B $\alpha$ (1-54) and ATP used in the inhibition studies were 0.56  $\mu$ M and 3  $\mu$ M, respectively. Enzymatic reactions (32  $\mu$ L) were carried out in wells of a 96 well assay plate for one hour at room temperature and terminated with the addition of trichloroacetic acid (TCA) (150  $\mu$ L/well of 12.5% w/v).



The subsequent 20 minute incubation with TCA precipitated the proteins but not peptides from solution. The TCA precipitate was collected on 96-well glass fiber plates (Packard) and washed 10 times with approximately 0.3 mL per well of Dulbecco's phosphate buffered saline pH 7.4 (Sigma) using a Packard Filtermate 196. Scintillation fluid (0.50 mL, MicroScint, Packard) was added to each well and the plate was analyzed for  $^{32}\text{P}$  using a Packard TopCount scintillation counter. Less than 10% of ATP was turned over in the course of the assay reaction, ensuring that the kinetic data represented initial rate data. The inhibition constant of the P32, 36 peptide was determined by Dixon analysis (Dixon and Webb, *In Enzymes* (Academic Press: New York, ed. 3, 1979), pp. 350-51.

10 The kinase displayed normal Michaelis-Menten kinetics, suggesting that it was not a mixture of diverse unrelated kinases. The kinase was capable of phosphorylating an I $\kappa$ B $\alpha$  (21-41) peptide (Figures 9A and 9B)) as well as two different I $\kappa$ B $\alpha$  (21-41) peptides, each bearing a free serine at either position 32 or 36 and phosphoserine at the other position (Figures 9A and 9B, lanes 2, 3). As expected, a peptide with phosphoserines at both positions was not phosphorylated at all (Figure 9B, top), indicating that there was no significant turnover of the phosphates under our reaction conditions. These experiments indicated that both serines 32 and 36 were phosphoacceptor sites for the IKK signalsome kinase, thus distinguishing it from other kinases such as pp90Rsk which phosphorylates I $\kappa$ B $\alpha$  only at serine 32 (Schouten, et al., 15 *EMBO J.* 16:3133-44, 1997).

Although the IKK signalsome kinase efficiently phosphorylated I $\kappa$ B peptides, it did not phosphorylate the c-Fos phosphopeptide containing a free serine and a free threonine (Figure 9B, top), two c-Jun peptides containing serine 63 and 73, respectively, (Figure 9A, top panel, lanes 4, 5), or an MKP-1 peptide containing four 25 serines and three threonines (Figure 9A, lane 6). The latter peptides were substrates for JNK2 (Figure 9A, bottom panel, lanes 4-6). An I $\kappa$ B $\alpha$  (21-41) peptide in which serines 32 and 36 were replaced by threonines was phosphorylated by the signalsome at least 10-fold less well than the wild-type serine-containing peptide, consistent with the slower phosphorylation and degradation kinetics of I $\kappa$ B $\alpha$  (S32/36 to T) in cells (DiDonato et al., 30 *Mol. Cell. Biol.* 16:1295-1304, 1996), and the preference of the kinase for serine over threonine at positions 32, 36 in both full-length I $\kappa$ B $\alpha$  and GST-I $\kappa$ B $\alpha$  (1-54) (Figures 8A

and C). In addition, the kinase phosphorylated GST-IkB $\beta$  (1-54), albeit with lower affinity. In most experiments, IkB kinase activity was also associated with strong RelA kinase activity (Figure 8C, lanes 3, 4), but no activity was observed towards several other substrates including myelin basic protein (MBP), GST-ATF2 (1-112), GST-cJun (1-79),  
5 GST-ERK3, GST-Elk (307-428), GST-p38, and a GST fusion protein containing the C-terminal region of IkB $\alpha$  (242-314).

The specificity of the IKK signalsome kinase was further emphasized by its susceptibility to product inhibition (Figure 9B, bottom). The kinase was strongly inhibited by a doubly-phosphorylated IkB $\alpha$  peptide bearing phosphoserines at both  
10 positions 32 and 36, but not by the unrelated c-Fos phosphopeptide that contained a single phosphothreonine. The singly-phosphorylated and the unphosphorylated IkB $\alpha$  peptides were less effective inhibitors.

#### Example 5

##### 15                   Absence of Free Ubiquitin in Purified IKK Signalsome

This example illustrates the absence of detectable free ubiquitin with a IKK signalsome prepared as in Example 3. Standard western blot procedures were performed (Amersham Life Science protocol, Arlington Heights, IL). 100 ng ubiquitin, 10 ng ubiquitin and 20 ul purified IkB $\alpha$  kinase complex was subjected to 16% Tricine  
20 SDS-PAGE (Novex, San Diego, CA), transferred to Hybond ECL Nitrocellulose membrane (Amersham Life Science, Arlington Heights, IL), and probed with antibodies directed against ubiquitin (MAB1510; Chemicon, Temecula, CA). The results are shown in Figure 10. Free ubiquitin could not be detected in the purified IkB $\alpha$  kinase preparation (even at very long exposures). The complexes described herein do not require addition of  
25 endogenous ubiquitin to detect IkB $\alpha$  kinase activity, nor is free ubiquitin a component in the purified IkB $\alpha$  kinase preparations of the present invention.

### Example 6

#### Purification of the NF $\kappa$ B Signalsome and Identification of IKK-1 and IKK-2

This Example illustrates a two-step affinity method for purification of the IKK signalsome, based on its recognition by the MKP-1 antibody (depicted in Figure 11A) and the identification of I $\kappa$ B kinases.

For large scale IKK signalsome purification, HeLa S3 cells were stimulated for 7 minutes with 20 ng/ml TNF $\alpha$  (R&D Systems, Minneapolis, MN), harvested, whole cell lysates were prepared (1.2 g total protein) and approximately 5 mg of anti-MKP-1 antibody (Santa Cruz Biotechnology, Inc., Santa Cruz, CA) was added and incubated at 4°C for 2 hours with gentle rotation. Subsequently, 50 ml of Protein A agarose (Calbiochem, San Diego, CA) was added and the mixture was incubated for an additional 2 hours. The immunoprecipitate was then sequentially washed 4X Pull-Down Buffer, 2X RIPA buffer, 2X Pull-Down Buffer, 1X 3.5 M urea-Pull-Down Buffer and 3X Pull-Down Buffer. The immunoprecipitate was then made into a thick slurry by the addition of 10 ml of Pull-Down Buffer, 25 mg of the specific MKP-1 peptide to which the antibody was generated (Santa Cruz Biotechnology, Inc., Santa Cruz, CA) was added, and the mixture was incubated overnight at 4°C with gentle rotation. The eluted IKK signalsome was then desalted on PD 10 desalting columns (Pharmacia Biotech, Piscataway, NJ) equilibrated with 50 mM Q buffer and chromatographed on a Mono Q column (Pharmacia Biotech, Piscataway, NJ). Fractions containing peak I $\kappa$ B kinase activity were pooled, concentrated and subjected to preparative SDS-PAGE. The intensity of two prominent protein bands of ~85 and ~87 kDa (indicated by silver stain in Figure 11B as IKK-1 and IKK-2 respectively) correlated with the profile of I $\kappa$ B kinase activity.

Coomassie stained ~85 and ~87 kDa bands were excised, in-gel digested with trypsin (Wilm et al., *Nature* 37:466-69, 1996) and a small aliquot of the supernatant was analyzed by high mass accuracy MALDI peptide mass mapping, as described by Shevchenko et al., *Proc. Natl. Acad. Sci. USA* 93:14440-45, 1996. The peptide mass map from the IKK-1 band was searched against a comprehensive protein sequence database using the program PeptideSearch developed in house at EMBL Heidelberg. Eight measured peptide masses matched calculated tryptic peptide masses from CHUK

(conserved helix-loop-helix ubiquitous kinase; Connely and Marcu, *Cell. Mol. Biol. Res.* 41:537-49, 1995) within 30 ppm, unambiguously identifying the protein. The peptide mass map of the IKK-2 band did not result in a clear identification and therefore the sample was subjected to nanoelectrospray mass spectrometry (Wilm and Mann, *Anal. Chem.* 68:1-8, 1996). The peptide mixture obtained after extraction of the gel piece was micropurified on a capillary containing 50 nL of POROS R2 resin (PerSeptive Biosystems, Framingham, MA). After washing, the peptides were step-eluted with 0.5 µl of 50% MeOH in 5% formic acid into a nanoelectrospray needle. This needle was transferred to an APIIII mass spectrometer (Perkin-Elmer, Sciex, Toronto, Canada) and the sample sprayed for approximately 20 minutes. During this time, peptide ions apparent from the mass spectrum were selected and isolated in turn and fragmented in the collision chamber of the mass spectrometer. From the tandem mass spectra, short stretches of sequence were assembled into peptide sequence tags (Mann and Wilm, *Anal. Chem.* 66:4390-99, 1994) and searched against a protein sequence database or against dbEST using PeptideSearch.

Three peptides matched the IKK-1 sequence. A1: IIDLGYAK (SEQ ID NO:17); A2: VEVALSNIK (SEQ ID NO:18); A3 SIQLDLER (SEQ ID NO:19). Three other peptides matched human EST sequences in dbEST: B1: ALELLPK (SEQ ID NO:20), B2: VIYTQLSK (SEQ ID NO:21), B6: LLLQAIQSFEK (SEQ ID NO:22) all match EST clone AA326115. The peptide B4 with the sequence LGTGGFGNVIR (SEQ ID NO:23) was found in clone R06591. After the full-length IKK-2 sequence was obtained (as described below) two more peptides B3: ALDDILNLK (SEQ ID NO:24) and B5: DLKPENIVLQQGEQR (SEQ ID NO:25) were found in the sequence. Peptide A1 is present in both IKK-1 and IKK-2 sequences. All the EST clones identified were clearly homologous to human and mouse CHUK, a serine/threonine kinase of hitherto unknown function. Once the complete coding sequence of IKK-2 was obtained (as described below), all sequenced peptides (apart from two peptides derived from IKK-1) could be assigned to this protein.

Representative mass spectra are shown in Figures 12A and 12B. In Figure 12A, peaks labeled A were matched to the tryptic peptides of IKK-1 upon fragmentation followed by database searching with peptide sequence tags. Peaks labeled B2, B4, B6

were not found in protein databases but instead matched human EST sequences. One more peptide (B1) matching a human EST clone was observed at  $m/z$  392.2 and is not shown in panel A. In Figure 12B, a continuous series of C-terminal-containing fragments (Y<sup>n</sup>- ions) was used to construct a peptide sequence tag as shown by boxed letters.

- 5 Search of this tag resulted in a match to the peptide LLLQALQSFEK (SEQ ID NO:22) in human EST clone AA326115. Two more peptides, B1 (ALELLPK; SEQ ID NO:20) and B2 (VIYTQLSK; SEQ ID NO:21) were found in the sequence of the same EST clone.

- Full-length human IKK-1 and IKK-2 cDNAs were cloned based on the human EST clones, which were obtained from Genome Systems, Inc. (St. Louis, MO).
- 10 The precise nucleotide sequences were determined and used to design primers to PCR clone human IKK-2 from a human HeLa cell cDNA library (Clontech, Inc., Palo Alto, CA). Several IKK-2 cDNA clones were isolated and sequenced. Full-length mouse IKK-1 and a partial human IKK-1 nucleotide sequence was available in the comprehensive database, primers were designed to PCR clone the respective human and mouse IKK-1
- 15 cDNAs. The partial human IKK-1 coding region was used to probe a HeLa cDNA phage library (Stratagene, Inc., La Jolla, CA) to obtain the full-length human IKK-1 cDNA clone using standard procedures.

- Sequence analysis of these clones revealed that IKK-1 and IKK-2 were related protein serine kinases (51% identity) containing protein interaction motifs (Figure
- 20 13A). Both IKK-1 and IKK-2 contain the kinase domain at the N-terminus, and a leucine zipper motif and a helix-loop-helix motif in their C-terminal regions (Figure 13A). Northern analysis indicated that mRNAs encoding IKK-2 were widely distributed in human tissues, with transcript sizes of ~4.5 kb and 6 kb (Figure 13B). The distribution of IKK-1 (CHUK) transcripts has been reported previously (Connely et al., *Cell. Mol. Biol. Res.* 41:537-49, 1995). IKK-1 and IKK-2 mRNAs are constitutively expressed in Jurkat,
- 25 HeLa and HUVEC cell lines, and their levels are not altered for up to 8 hours following stimulation with NF $\kappa$ B-inducers such as TNF $\alpha$  (HeLa, HUVEC)-or anti-CD28 plus PMA (Jurkat).

- To further characterize the properties of IKK-1 and IKK-2, recombinant
- 30 HA-tagged IKK-1 and Flag-tagged IKK-2, either separately or alone, were *in vitro* transcribed and translated in wheat germ or rabbit reticulocyte lysate (Promega, Madison.

WI). The reactions were performed exactly as described in the manufacturer's protocol. Epitope-tagged IKK-1 and IKK-2 then immunoprecipitated with the appropriate anti-tag antibody. Immunoprecipitates containing these proteins phosphorylated I $\kappa$ B $\alpha$  and I $\kappa$ B $\beta$  with the correct substrate specificity (*i.e.*, immunoprecipitates of IKK-1 and IKK-2 phosphorylated both GST-I $\kappa$ B $\alpha$  (Figure 14A, panel 3) and GST-I $\kappa$ B $\beta$  (panel 4), but did not phosphorylate the corresponding S32/36 to T<sub>1</sub> mutant protein). IKK-1 expressed in rabbit reticulocyte lysates was also capable of autophosphorylation (Figure 14A, panel 2, lane 1), whereas a kinase-inactive version of IKK-1, in which the conserved lysine 44 had been mutated to methionine, showed no autophosphorylation. In contrast IKK-2, although expressed at equivalent levels in the lysates (panel 1), showed very weak autophosphorylation (panel 2, lane 2).

Expression of the kinase inactive mutants (K to M) of IKK-1 and IKK-2 indicate that both play critical roles in NF $\kappa$ B activation as demonstrated by immunofluorescent studies (Figures 14B and 14C). For these studies, HeLa cells were transiently transfected with either HA-tagged IKK-1 or Flag-tagged IKK-2. Cells were fixed for 30 minutes with methanol. For immunofluorescence staining, the cells were incubated sequentially with primary antibody in PBS containing 10% donkey serum and 0.25% Triton X-100 for 2 hours followed by fluorescein-conjugated or Texas red-conjugated secondary antibody (Jackson ImmunoResearch Laboratories, Inc., West Grove, PA; used at 1:500 dilution) for 1 hour at room temperature. The coverslips were rinsed and coverslipped with Vectashield (Vector Laboratories, Burlingame, CA) before scoring and photographing representative fields. Primary antibodies used for immunofluorescence staining included antibodies against Rel A (Santa Cruz Biotechnology, Inc., Santa Cruz, CA), HA tag (Babco, Berkeley, CA) and Flag tag (IBI-Kodak, New Haven, CT).

Kinase-inactive versions (K44 to M) of IKK-1 and IKK-2 had no effect on the subcellular localization of RelA in unstimulated HeLa cells, since RelA remained cytoplasmic both in cells expressing the epitope-tagged proteins and in the adjacent untransfected cells (Figures 14B and 14C, top panels). In contrast, both mutant proteins inhibited RelA nuclear translocation in TNF $\alpha$ -stimulated cells (Figures 14B and 14C, bottom panels). The inhibition mediated by the IKK-2 mutant was striking and complete

(Figure 14C: compare mutant IKK-2-expressing cells with untransfected cells in the same field), whereas that mediated by the mutant IKK-1 protein, expressed at apparently equivalent levels, was significant but incomplete (Figure 14B). This difference in the functional activities of the two mutant kinases may point to distinct roles for these two  
5 kinases in NF $\kappa$ B activation.

The presence of the leucine zipper and helix-loop-helix motif in IKK-1 and IKK-2 suggested that they interacted functionally with other proteins in the signalsome. An obvious possibility was that the proteins formed hetero- or homodimers with one another. HA-tagged IKK-1 and FLAG-tagged IKK-2 were translated in rabbit  
10 reticulocyte lysates, either alone or together, and then immunoprecipitated with antibodies to the appropriate epitope tags. This experiment demonstrated clearly that IKK-2 was present in IKK-1 immunoprecipitates (Figure 15A, lane 3) and vice versa (lane 4), suggesting that these proteins either associated directly or via adapter proteins/IKK signalsome components present in the rabbit reticulocyte lysates. In contrast, however,  
15 there was no evidence for association of IKK-1 and IKK-2 that had been cotranslated in wheat germ lysates (Figure 15B), suggesting that the proteins did not heterodimerize directly. When full-length IKK-1 was translated together in wheat germ extracts with a truncated version of IKK-1 that still possessed the protein interaction motifs, there was also no evidence of association, suggesting that IKK-1 was also not capable of forming  
20 homodimers under these conditions.

Both IKK-1 and IKK-2 kinases were active when expressed in wheat germ extracts, since they were capable of autophosphorylation, but they were inactive with respect to phosphorylation of I $\kappa$ B substrates. Since both autophosphorylation and substrate phosphorylation were intact in rabbit reticulocyte lysates, there appeared to be a  
25 direct correlation between the association of IKK-1 and IKK-2 into a higher order protein complex and the presence of specific I $\kappa$ B kinase activity in IKK-1 and IKK-2 immunoprecipitates. This higher order complex is most likely the IKK signalsome itself. Indeed, immunoprecipitation of rabbit reticulocyte lysates with anti-MKP-1 antibody pulls down a low level of active I $\kappa$ B kinase activity characteristic of the IKK signalsome.

30 It is clear that the IKK signalsome contains multiple protein components in addition to IKK-1 and IKK-2 (Figure 11B). Some of these may be upstream kinases

such as MEKK-1 (Chen et al., *Cell* 84:853-62, 1996) or NIK (Malinin, et al., *Nature* 385:540-44, 1997); others may be adapter proteins that mediate the IKK-1:IKK-2 interaction. Indeed MEKK-1 copurifies with IKK signalsome activity (Figure 1C), and two other signalsome proteins have been functionally identified. The protein crossreactive with anti-MKP-1 is an intrinsic component of the IKK signalsome kinases, since the I $\kappa$ B kinase activity coprecipitated with this antibody is stable to washes with 2-4 M urea. Moreover, both IKK-1 immunoprecipitates and MKP-1 immunoprecipitates containing the IKK signalsome (Figure 8C) contain an inducible RelA kinase whose kinetics of activation parallel those of the I $\kappa$ B kinase in the same immunoprecipitates.

10 Another strong candidate for a protein in the signalsome complex is the E3 ubiquitin ligase that transfers multiubiquitin chains to phosphorylated I $\kappa$ B (Hershko et al., *Annu. Rev. Biochem.* 61:761-807, 1992).

These results indicate that IKK-1 and IKK-2 are functional kinases within the IKK signalsome, which mediate I $\kappa$ B phosphorylation and NF $\kappa$ B activation.

15 Appropriate regulation of IKK-1 and IKK-2 may require their assembly into a higher order protein complex, which may be a heterodimer facilitated by adapter proteins, the complete IKK signalsome, or some intermediate subcomplex that contains both IKK-1 and IKK-2.

20 From the foregoing, it will be appreciated that, although specific embodiments of the invention have been described herein for the purpose of illustration, various modifications may be made without deviating from the spirit and scope of the invention.



## SEQUENCE LISTING

## (1) GENERAL INFORMATION:

(i) APPLICANTS: Mercurio, Frank  
Zhu, Hengyi  
Barbosa, Miguel  
Li, Gian  
Murray, Brion W.

(ii) TITLE OF INVENTION: STIMULUS-INDUCIBLE PROTEIN KINASE  
COMPLEX AND METHODS OF USE THEREFOR

(iii) NUMBER OF SEQUENCES: 25

## (iv) CORRESPONDENCE ADDRESS:

(A) ADDRESSEE: SEED and BERRY LLP  
(B) STREET: 6300 Columbia Center, 701 Fifth Avenue  
(C) CITY: Seattle  
(D) STATE: Washington  
(E) COUNTRY: USA  
(F) ZIP: 98104

## (v) COMPUTER READABLE FORM:

(A) MEDIUM TYPE: Floppy disk  
(B) COMPUTER: IBM PC compatible  
(C) OPERATING SYSTEM: PC-DOS/MS-DOS  
(D) SOFTWARE: PatentIn Release #1.0, Version #1.30

## (vi) CURRENT APPLICATION DATA:

(A) APPLICATION NUMBER: US  
(B) FILING DATE: 12-AUG-1997  
(C) CLASSIFICATION:

## (viii) ATTORNEY/AGENT INFORMATION:

(A) NAME: Maki, David J.

(B) REGISTRATION NUMBER: 31,392

(C) REFERENCE/DOCKET NUMBER: 860098.413C1

(ix) TELECOMMUNICATION INFORMATION:

(A) TELEPHONE: (206) 622-4900

(B) TELEFAX: (206) 682-6031

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 317 amino acids

(B) TYPE: amino acid

(C) STRANDEDNESS:

(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

Met Phe Gln Ala Ala Glu Arg Pro Gln Glu Trp Ala Met Glu Gly Pro  
1                    5                    10                    15

Arg Asp Gly Leu Lys Lys Glu Arg Leu Leu Asp Asp Arg His Asp Ser  
20                    25                    30

Gly Leu Asp Ser Met Lys Asp Glu Glu Tyr Glu Gln Met Val Lys Glu  
35                    40                    45

Leu Gln Glu Ile Arg Leu Glu Pro Gln Glu Val Pro Arg Gly Ser Glu  
50                    55                    60

Pro Trp Lys Gln Gln Leu Thr Glu Asp Gly Asp Ser Phe Leu His Leu  
65                    70                    75                    80

Ala Ile Ile His Glu Glu Lys Ala Leu Thr Met Glu Val Ile Arg Gln  
85 90 95

Val Lys Gly Asp Leu Ala Phe Leu Asn Phe Gln Asn Asn Leu Gln Gln  
100 105 110

Thr Pro Leu His Leu Ala Val Ile Thr Asn Gln Pro Glu Ile Ala Glu  
115 120 125

Ala Leu Leu Gly Ala Gly Cys Asp Pro Glu Leu Arg Asp Phe Arg Gly  
130 135 140

Asn Thr Pro Leu His Leu Ala Cys Glu Gln Gly Cys Leu Ala Ser Val  
145 150 155 160

Gly Val Leu Thr Gln Ser Cys Thr Thr Pro His Leu His Ser Ile Leu  
165 170 175

Lys Ala Thr Asn Tyr Asn Gly His Thr Cys Leu His Leu Ala Ser Ile  
180 185 190

His Gly Tyr Leu Gly Ile Val Glu Leu Leu Val Ser Leu Gly Ala Asp  
195 200 205

Val Asn Ala Gln Glu Pro Cys Asn Gly Arg Thr Ala Leu His Leu Ala  
210 215 220

Val Asp Leu Gln Asn Pro Asp Leu Val Ser Leu Leu Leu Lys Cys Gly  
225 230 235 240

Ala Asp Val Asn Arg Val Thr Tyr Gln Gly Tyr Ser Pro Tyr Gln Leu  
245 250 255

Thr Trp Gly Arg Pro Ser Thr Arg Ile Gln Gln Gln Leu Gly Gln Leu  
260 265 270

Thr Leu Glu Asn Leu Gln Met Leu Pro Glu Ser Glu Asp Glu Glu Ser

275                                      280                                      285  
 Tyr Asp Thr Glu Ser Glu Phe Thr Glu Phe Thr Glu Asp Glu Leu Pro  
 290                                      295                                      300

Tyr Asp Asp Cys Val Phe Gly Gly Gln Arg Leu Thr Leu  
 305                                      310                                      315

## (2) INFORMATION FOR SEQ ID NO:2:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 359 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met Ala Gly Val Ala Cys Leu Gly Lys Thr Ala Asp Ala Asp Glu Trp  
 1                                      5                                      10                                      15

Cys Asp Ser Gly Leu Gly Ser Leu Gly Pro Asp Ala Ala Ala Pro Gly  
 20                                      25                                      30

Gly Pro Gly Leu Gly Ala Glu Leu Gly Pro Glu Leu Ser Trp Ala Pro  
 35                                      40                                      45

Leu Val Phe Gly Tyr Val Thr Glu Asp Gly Asp Thr Ala Leu His Leu  
 50                                      55                                      60

Ala Val Ile His Gln His Glu Pro Phe Leu Asp Phe Leu Leu Gly Phe  
 65                                      70                                      75                                      80

Ser Ala Gly His Glu Tyr Leu Asp Leu Gln Asn Asp Leu Gly Gln Thr  
85 90 95

Ala Leu His Leu Ala Ala Ile Leu Gly Glu Ala Ser Thr Val Glu Lys  
100 105 110

Leu Tyr Ala Ala Gly Ala Gly Val Leu Val Ala Glu Arg Gly Gly His  
115 120 125

Thr Ala Leu His Leu Ala Cys Arg Val Arg Ala His Thr Cys Ala Cys  
130 135 140

Val Leu Leu Gln Pro Arg Pro Ser His Pro Arg Asp Ala Ser Asp Thr  
145 150 155 160

Tyr Leu Thr Gln Ser Gln Asp Cys Thr Pro Asp Thr Ser His Ala Pro  
165 170 175

Ala Ala Val Asp Ser Gln Pro Asn Pro Glu Asn Glu Glu Glu Pro Arg  
180 185 190

Asp Glu Asp Trp Arg Leu Gln Leu Glu Ala Glu Asn Tyr Asp Gly His  
195 200 205

Thr Pro Leu His Val Ala Val Ile His Lys Asp Ala Glu Met Val Arg  
210 215 220

Leu Leu Arg Asp Ala Gly Ala Asp Leu Asn Lys Pro Glu Pro Thr Cys  
225 230 235 240

Gly Arg Thr Pro Leu His Leu Ala Val Glu Ala Gln Ala Ala Ser Val  
245 250 255

Leu Glu Leu Leu Leu Lys Ala Gly Ala Asp Pro Thr Ala Arg Met Tyr  
260 265 270

Gly Gly Arg Thr Pro Leu Gly Ser Ala Leu Leu Arg Pro Asn Pro Ile

275                      280                      285  
 Leu Ala Arg Leu Leu Arg Ala His Gly Ala Pro Glu Pro Glu Asp Glu  
 290                      295                      300  
 Asp Asp Lys Leu Ser Pro Cys Ser Ser Ser Gly Ser Asp Ser Asp Ser  
 305                      310                      315                      320  
 Asp Asn Arg Asp Glu Gly Asp Glu Tyr Asp Asp Ile Val Val His Ser  
 325                      330                      335  
 Gly Arg Ser Gln Asn Arg Gln Pro Pro Ser Pro Ala Ser Lys Pro Leu  
 340                      345                      350  
 Pro Asp Asp Pro Asn Pro Ala  
 355

## (2) INFORMATION FOR SEQ ID NO:3:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 282 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

Met Ser Pro Ile Leu Gly Tyr Trp Lys Ile Lys Gly Leu Val Gln Pro  
 1                      5                      10                      15  
 Thr Arg Leu Leu Leu Glu Tyr Leu Glu Glu Lys Tyr Glu Glu His Leu  
 20                      25                      30

Tyr Glu Arg Asp Glu Gly Asp Lys Trp Arg Asn Lys Lys Phe Glu Leu  
 35 40 45

Gly Leu Glu Phe Pro Asn Leu Pro Tyr Tyr Ile Asp Gly Asp Val Lys  
 50 55 60

Leu Thr Gln Ser Met Ala Ile Ile Arg Tyr Ile Ala Asp Lys His Asn  
 65 70 75 80

Met Leu Gly Gly Cys Pro Lys Glu Arg Ala Glu Ile Ser Met Leu Glu  
 85 90 95

Gly Ala Val Leu Asp Ile Arg Tyr Gly Val Ser Arg Ile Ala Tyr Ser  
 100 105 110

Lys Asp Phe Glu Thr Leu Lys Val Asp Phe Leu Ser Lys Leu Pro Glu  
 115 120 125

Met Leu Lys Met Phe Glu Asp Arg Leu Cys His Lys Thr Tyr Leu Asn  
 130 135 140

Gly Asp His Val Thr His Pro Asp Phe Met Leu Tyr Asp Ala Leu Asp  
 145 150 155 160

Val Val Leu Tyr Met Asp Pro Met Cys Leu Asp Ala Phe Pro Lys Leu  
 165 170 175

Val Cys Phe Lys Lys Arg Ile Glu Ala Ile Pro Gln Ile Asp Lys Tyr  
 180 185 190

Leu Lys Ser Ser Lys Tyr Ile Ala Trp Pro Leu Gln Gly Trp Gln Ala  
 195 200 205

Thr Phe Gly Gly Gly Asp His Pro Pro Lys Ser Asp Pro Arg Glu Phe  
 210 215 220

Ile Val Thr Asp Met Phe Gln Ala Ala Glu Arg Pro Gln Glu Trp Ala

225	230	235	240
Met Glu Gly Pro Arg Asp Gly Leu Lys Lys Glu Arg Leu Leu Asp Asp			
	245	250	255
Arg His Asp Ser Gly Leu Asp Ser Met Lys Asp Glu Glu Tyr Glu Gln			
	260	265	270
Met Val Lys Glu Leu Gln Glu Ile Arg Leu			
	275	280	

## (2) INFORMATION FOR SEQ ID NO:4:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 272 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

Met Ser Pro Ile Leu Gly Tyr Trp Lys Ile Lys Gly Leu Val Gln Pro			
1	5	10	15
Thr Arg Leu Leu Leu Glu Tyr Leu Glu Glu Lys Tyr Glu Glu His Leu			
	20	25	30
Tyr Glu Arg Asp Glu Gly Asp Lys Trp Arg Asn Lys Lys Phe Glu Leu			
	35	40	45
Gly Leu Glu Phe Pro Asn Leu Pro Tyr Tyr Ile Asp Gly Asp Val Lys			
	50	55	60



Leu Thr Gln Ser Met Ala Ile Ile Arg Tyr Ile Ala Asp Lys His Asn  
65 70 75 80

Met Leu Gly Gly Cys Pro Lys Glu Arg Ala Glu Ile Ser Met Leu Glu  
85 90 95

Gly Ala Val Leu Asp Ile Arg Tyr Gly Val Ser Arg Ile Ala Tyr Ser  
100 105 110

Lys Asp Phe Glu Thr Leu Lys Val Asp Phe Leu Ser Lys Leu Pro Glu  
115 120 125

Met Leu Lys Met Phe Glu Asp Arg Leu Cys His Lys Thr Tyr Leu Asn  
130 135 140

Gly Asp His Val Thr His Pro Asp Phe Met Leu Tyr Asp Ala Leu Asp  
145 150 155 160

Val Val Leu Tyr Met Asp Pro Met Cys Leu Asp Ala Phe Pro Lys Leu  
165 170 175

Val Cys Phe Lys Lys Arg Ile Glu Ala Ile Pro Gln Ile Asp Lys Tyr  
180 185 190

Leu Lys Ser Ser Lys Tyr Ile Ala Trp Pro Leu Gln Gly Trp Gln Ala  
195 200 205

Thr Phe Gly Gly Gly Asp His Pro Pro Lys Ser Asp Pro Arg Glu Phe  
210 215 220

Ile Val Thr Asp Met Ala Gly Val Ala Cys Leu Gly Lys Thr Ala Asp  
225 230 235 240

Ala Asp Glu Trp Cys Asp Ser Gly Leu Gly Ser Leu Gly Pro Asp Ala  
245 250 255

Ala Ala Pro Gly Gly Pro Gly Leu Gly Ala Glu Leu Gly Pro Glu Leu

260

265

270

## (2) INFORMATION FOR SEQ ID NO:5:

## (i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 282 amino acids

(B) TYPE: amino acid

(C) STRANDEDNESS:

(D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

Met Ser Pro Ile Leu Gly Tyr Trp Lys Ile Lys Gly Leu Val Gln Pro  
 1 5 10 15

Thr Arg Leu Leu Leu Glu Tyr Leu Glu Glu Lys Tyr Glu Glu His Leu  
 20 25 30

Tyr Glu Arg Asp Glu Gly Asp Lys Trp Arg Asn Lys Lys Phe Glu Leu  
 35 40 45

Gly Leu Glu Phe Pro Asn Leu Pro Tyr Tyr Ile Asp Gly Asp Val Lys  
 50 55 60

Leu Thr Gln Ser Met Ala Ile Ile Arg Tyr Ile Ala Asp Lys His Asn  
 65 70 75 80

Met Leu Gly Gly Cys Pro Lys Glu Arg Ala Glu Ile Ser Met Leu Glu  
 85 90 95

Gly Ala Val Leu Asp Ile Arg Tyr Gly Val Ser Arg Ile Ala Tyr Ser  
 100 105 110

Lys Asp Phe Glu Thr Leu Lys Val Asp Phe Leu Ser Lys Leu Pro Glu

115

120

125

Met Leu Lys Met Phe Glu Asp Arg Leu Cys His Lys Thr Tyr Leu Asn

130

135

140

Gly Asp His Val Thr His Pro Asp Phe Met Leu Tyr Asp Ala Leu Asp

145

150

155

160

Val Val Leu Tyr Met Asp Pro Met Cys Leu Asp Ala Phe Pro Lys Leu

165

170

175

Val Cys Phe Lys Lys Arg Ile Glu Ala Ile Pro Gln Ile Asp Lys Tyr

180

185

190

Leu Lys Ser Ser Lys Tyr Ile Ala Trp Pro Leu Gln Gly Trp Gln Ala

195

200

205

Thr Phe Gly Gly Gly Asp His Pro Pro Lys Ser Asp Pro Arg Glu Phe

210

215

220

Ile Val Thr Asp Met Phe Gln Ala Ala Glu Arg Pro Gln Glu Trp Ala

225

230

235

240

Met Glu Gly Pro Arg Asp Gly Leu Lys Lys Glu Arg Leu Leu Asp Asp

245

250

255

Arg His Asp Thr Gly Leu Asp Thr Met Lys Asp Glu Glu Tyr Glu Gln

260

265

270

Met Val Lys Glu Leu Gln Glu Ile Arg Leu

275

280

(2) INFORMATION FOR SEQ ID NO:6:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 272 amino acids  
 (B) TYPE: amino acid  
 (C) STRANDEDNESS:  
 (D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

Met Ser Pro Ile Leu Gly Tyr Trp Lys Ile Lys Gly Leu Val Gln Pro  
 1 5 10 15

Thr Arg Leu Leu Leu Glu Tyr Leu Glu Glu Lys Tyr Glu Glu His Leu  
 20 25 30

Tyr Glu Arg Asp Glu Gly Asp Lys Trp Arg Asn Lys Lys Phe Glu Leu  
 35 40 45

Gly Leu Glu Phe Pro Asn Leu Pro Tyr Tyr Ile Asp Gly Asp Val Lys  
 50 55 60

Leu Thr Gln Ser Met Ala Ile Ile Arg Tyr Ile Ala Asp Lys His Asn  
 65 70 75 80

Met Leu Gly Gly Cys Pro Lys Glu Arg Ala Glu Ile Ser Met Leu Glu  
 85 90 95

Gly Ala Val Leu Asp Ile Arg Tyr Gly Val Ser Arg Ile Ala Tyr Ser  
 100 105 110

Lys Asp Phe Glu Thr Leu Lys Val Asp Phe Leu Ser Lys Leu Pro Glu  
 115 120 125

Met Leu Lys Met Phe Glu Asp Arg Leu Cys His Lys Thr Tyr Leu Asn  
 130 135 140

Gly Asp His Val Thr His Pro Asp Phe Met Leu Tyr Asp Ala Leu Asp  
 145 150 155 160

Val Val Leu Tyr Met Asp Pro Met Cys Leu Asp Ala Phe Pro Lys Leu  
 165 170 175

Val Cys Phe Lys Lys Arg Ile Glu Ala Ile Pro Gln Ile Asp Lys Tyr  
 180 185 190

Leu Lys Ser Ser Lys Tyr Ile Ala Trp Pro Leu Gln Gly Trp Gln Ala  
 195 200 205

Thr Phe Gly Gly Gly Asp His Pro Pro Lys Ser Asp Pro Arg Glu Phe  
 210 215 220

Ile Val Thr Asp Met Ala Gly Val Ala Cys Leu Gly Lys Thr Ala Asp  
 225 230 235 240

Ala Asp Glu Trp Cys Asp Ala Gly Leu Gly Ala Leu Gly Pro Asp Ala  
 245 250 255

Ala Ala Pro Gly Gly Pro Gly Leu Gly Ala Glu Leu Gly Pro Glu Leu  
 260 265 270

(2) INFORMATION FOR SEQ ID NO:7:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 2251 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

GGCACGAGGC CCCATGGAGC GGCCCCCGGG GCTGCGGCCG GGCGCGGGCG GGCCCTGGGA	60
GATGCGGGAG CGGCTGGGCA CCGGCGGCTT CGGGAACGTC TGTCTGTACC AGCATCGGGA	120
ACTTGATCTC AAAATAGCAA TTAAGTCTTG TCGCCTAGAG CTAAGTACCA AAAACAGAGA	180
ACGATGGTGC CATGAAATCC AGATTATGAA GAAGTTGAAC CATGCCAATG TTGTAAAGGC	240
CTGTGATGTT CCTGAAGAAT TGAATATTTT GATTCATGAT GTGCCTCTTC TAGCAATGGA	300
ATACTGTTCT GGAGGAGATC TCCGAAAGCT GCTCAACAAA CCAGAAAATT GTTGTGGACT	360
TAAAGAAAGC CAGATACTTT CTTTACTAAG TGATATAGGG TCTGGGATTC GATATTTGCA	420
TGAAAACAAA ATTATACATC GAGATCTAAA ACCTGAAAAC ATAGTTCTTC AGGATGTTGG	480
TGGAAAGATA ATACATAAAA TAATTGATCT GGGATATGCC AAAGATGTTG ATCAAGGAAG	540
TCTGTGTACA TCTTTTGTGG GAACACTGCA GTATCTGGCC CCAGAGCTCT TTGAGAATAA	600
GCCTTACACA GCCACTGTTG ATTATTGGAG CTTTGGGACC ATGGTATTTG AATGTATTGC	660
TGGATATAGG CCTTTTTTGC ATCATCTGCA GCCATTTACC TGGCATGAGA AGATTAAGAA	720
GAAGGATCCA AAGTGATATAT TTGCATGTGA AGAGATGTCA GGAGAAGTTC GGTTTAGTAG	780
CCATTTACCT CAACCAAATA GCCTTTGTAG TTTAATAGTA GAACCCATGG AAAACTGGCT	840
ACAGTTGATG TTGAATTGGG ACCCTCAGCA GAGAGGAGGA CCTGTTGACC TTACTTTGAA	900
GCAGCCAAGA TGTTTTGTAT TAATGGATCA CATTTTGAAT TTGAAGATAG TACACATCCT	960
AAATATGACT TCTGCAAAGA TAATTTCTTT TCTGTTACCA CCTGATGAAA GTCTTCATTC	1020

ACTACAGTCT CGTATTGAGC GTGAAACTGG AATAAATACT GGTTCCTCAAG AACTTCTTTC 1080  
AGAGACAGGA ATTTCTCTGG ATCCTCGGAA ACCAGCCTCT CAATGTGTTC TAGATGGAGT 1140  
TAGAGGCTGT GATAGCTATA TGGTTTATTT GTTTGATAAA AGTAAACTG TATATGAAGG 1200  
GCCATTTGCT TCCAGAAGTT TATCTGATTG TGTAATTAT ATTGTACAGG ACAGCAAAAT 1260  
ACAGCTTCCA ATTATACAGC TCGGTAAAGT GTGGGCTGAA GCAGTGCAC TGTGTCTGG 1320  
ACTAAAAGAA GACTATAGCA GGCTCTTTC GGGACAAAG GCAGCAATGT TAAGTCTTCT 1380  
TAGATATAAT GCTAACTTAA CAAAATGAA GAACACTTTG ATCTCAGCAT CACAACAACT 1440  
GAAAGCTAAA TTGGAGTTTT TTCACAAAAG CATTGAGCTT GACTTGGAGA GATACAGCGA 1500  
GCAGATGACG TATGGGATAT CTTGAGAAAA AATGCTAAAA GCATGGAAAG AAATGGAAGA 1560  
AAAGGCCATC CACTATGCTG AGGTTGGTGT CATTGGATAC CTGGAGGATC AGATTATGTC 1620  
TTTGCATGCT GAAATCATGG AGCTACAGAA GAGCCCCTAT GGAAGACGTC AGGGAGACTT 1680  
GATGGAATCT CTGGAACAGC GTGCCATTGA TCTATATAAG CAGTTAAAAC ACAGACCTTC 1740  
AGATCACTCC TACAGTGACA GCACAGAGAT GGTGAAAATC ATTGTGCACA CTGTGCAGAG 1800  
TCAGGACCGT GTGCTCAAGG AGCGTTTTGG TCATTGAGC AAGTTGTTGG GCTGTAAGCA 1860  
GAAGATTATT GATCTACTCC CTAAGGTGGA AGTGGCCCTC AGTAATATCA AAGAAGCTGA 1920  
CAATACTGTC ATGTTTATGC AGGGAAAAAG GCAGAAAGAA ATATGGCATC TCCTTAAAT 1980  
TGCCTGTACA CAGAGTTCTG CCCGCTCTCT TGTAGGATCC AGTCTAGAAG GTGCAGTAAC 2040  
CCCTCAAGCA TACGCATGGC TGGCCCCCGA CTTAGCAGAA CATGATCATT CTCTGTCATG 2100  
TGTGGTAACT CCTCAAGATG GGGAGACTTC AGCACAAATG ATAGAAGAAA ATTTGAACTG 2160

CCTTGCCAT TTAAGCACTA TTATTCATGA GGCAANTGAG GAACAGGGCA ATAGTATGAT 2220  
GAATCTTGAT TGGAGTTGGT TAACAGAATG A 2251

(2) INFORMATION FOR SEQ ID NO:8:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 2271 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

ATGAGCTGGT CACCTTCCCT GACAACGCAG ACATGTGGGG CCTGGGAAAT GAAAGAGCGC 60  
CTTGGGACAG GGGGATTGG AAATGTCATC CGATGGCACA ATCAGGAAAC AGGTGAGCAG 120  
ATTGCCATCA AGCAGTGCCG GCAGGAGCTC AGCCCCCGGA ACCGAGAGCG GTGGTGCCTG 180  
GAGATCCAGA TCATGAGAAG GCTGACCCAC CCCAATGTGG TGGCTGCCCG AGATGTCCCT 240  
GAGGGGATGC AGAACTTGGC GCCCAATGAC CTGCCCCTGC TGGCCATGGA GTACTGCCAA 300  
GGAGGAGATC TCCGGAAGTA CCTGAACCAG TTTGAGAACT GCTGTGGTCT GCGGGAAGGT 360  
GCCATCCTCA CCTTGCTGAG TGACATTGCC TCTGCGCTTA GATACCTTCA TGAAAACAGA 420  
ATCATCCATC GGGATCTAAA GCCAGAAAAC ATCGTCCTGC AGCAAGGAGA ACAGAGGTTA 480  
ATACACAAAA TTATTGACCT AGGATATGCC AAGGAGCTGG ATCAGGGCAG TCTTTGCACA 540



TCATTCGTGG GGACCCTGCA GTACCTGGCC CCAGAGCTAC TGGAGCAGCA GAAGTACACA 600

GTGACCGTCG ACTACTGGAG CTTCCGGCACC CTGGCCTTTG AGTGCATCAC GGGCTTCCGG 660

CCCTTCCTCC CCAACTGGCA GCCCCTGCAG TGGCATTCAA AAGTGCGGCA GAAGAGTGAG 720

GTGGACATTG TTGTTAGCGA AGACTTGAAT GGAACGGTGA AGTTTTCAAG CTCTTTACCC 780

TACCCAATA ATCTTAACAG TGTCTGGCT GAGCGACTGG AGAAGTGGCT GCAACTGATG 840

CTGATGTGGC ACCCCCGACA GAGGGGCACG GATCCACAGT ATGGGCCCAA TGGCTGCTTC 900

AAGGCCCTGG ATGACATCTT AACTTAAAG TTGGTTCATA TCTTGAACAT GGTACGGGC 960

ACCATCCACA CCTACCCTGT GACAGAGGAT GAGAGTCTGC AGAGCTTGAA GGCCAGAATC 1020

CAACAGGACA CGGGCATCCC AGAGGAGGAC CAGGAGCTGC TGCAGGAAGC GGGCCTGGCG 1080

TTGATCCCCG ATAAGCCTGC CACTCAGTGT ATTTAGACG GCAAGTTAAA TGAGGGCCAC 1140

ACATTGGACA TGGATCTTGT TTTTCTCTTT GACAACAGTA AAATCACCTA TGAGACTCAG 1200

ATCTCCCCAC GGCCCCAACC TGAAAGTGTC AGCTGTATCC TTCAAGAGCC CAAGAGGAAT 1260

CTCGCCTTCT TCCACCTGAG GAAGGTGTGG GGCCAGGTCT GGCACAGCAT CCAGACCCTG 1320

AAGGAAGATT GCAACCGGCT GCAGCAGGGA CAGCGAGCCG CCATGATGAA TCTCTCCGA 1380

AACAACAGCT GCCTCTCCAA AATGAAGAAT TCCATGGCTT CCATGTCTCA GCAGCTCAAG 1440

GCCAAGTTGG ATTTCTTCAA AACCAGCATC CAGATTGACC TGGAGAAGTA CAGCGAGCAA 1500

ACCGAGTTTG GGATCACATC AGATAAACTG CTGCTGGCCT GGAGGGAAAT GGAGCAGGCT 1560

GTGGAGCTCT GTGGGCGGGA GAACGAAGTG AACTCCTGG TAGAACGGAT GATGGCTCTG 1620

CAGACCGACA TTGTGGACTT ACAGAGGAGC CCCATGGGCC GGAAGCAGGG GGAACGCTG 1680

GACGACCTAG AGGAGCAAGC AAGGGAGCTG TACAGGAGAC TAAGGGAAAA ACCTCGAGAC 1740  
CAGCGAACTG AGGGTGACAG TCAGGAAATG GTACGGCTGC TGCTTCAGGC AATTCAGAGC 1800  
TTCGAGAAGA AAGTGCGAGT GATCTATACG CAGCTCAGTA AAAGTGTGGT TTGCAAGCAG 1860  
AAGGCCCTGG AACTGTTGCC CAAGGTGGAA GAGGTGGTGA GCTTAATGAA TGAGGATGAG 1920  
AAGACTGTTG TCCGGCTGCA GGAGAAGCGG CAGAAGGAGC TCTGGAATCT CCTGAAGATT 1980  
GCTTGTAAGCA AGGTCCGTGG TCCTGTCAGT GGAAGCCCGG ATAGCATGAA TGCCTCTCGA 2040  
CTTAGCCAGC CTGGGCAGCT GATGTCTCAG CCCTCCACGG CCTCCAACAG CTTACCTGAG 2100  
CCAGCCAAGA AGAGTGAAGA ACTGGTGGCT GAAGCACATA ACCTCTGCAC CCTGCTAGAA 2160  
AATGCCATAC AGGACACTGT GAGGGAACAA GACCAGAGTT TCACGGCCCT AGACTGGAGC 2220  
TGGTTACAGA CGGAAGAAGA AGAGCACAGC TGCCTGGAGC AGGCCTCATG A 2271

(2) INFORMATION FOR SEQ ID NO:9:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 756 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

Met Ser Trp Ser Pro Ser Leu Thr Thr Gln Thr Cys Gly Ala Trp Glu  
1 5 10 15

Met Lys Glu Arg Leu Gly Thr Gly Gly Phe Gly Asn Val Ile Arg Trp

20

25

30

His Asn Gln Glu Thr Gly Glu Gln Ile Ala Ile Lys Gln Cys Arg Gln

35

40

45

Glu Leu Ser Pro Arg Asn Arg Glu Arg Trp Cys Leu Glu Ile Gln Ile

50

55

60

Met Arg Arg Leu Thr His Pro Asn Val Val Ala Ala Arg Asp Val Pro

65

70

75

80

Glu Gly Met Gln Asn Leu Ala Pro Asn Asp Leu Pro Leu Leu Ala Met

85

90

95

Glu Tyr Cys Gln Gly Gly Asp Leu Arg Lys Tyr Leu Asn Gln Phe Glu

100

105

110

Asn Cys Cys Gly Leu Arg Glu Gly Ala Ile Leu Thr Leu Leu Ser Asp

115

120

125

Ile Ala Ser Ala Leu Arg Tyr Leu His Glu Asn Arg Ile Ile His Arg

130

135

140

Asp Leu Lys Pro Glu Asn Ile Val Leu Gln Gln Gly Glu Gln Arg Leu

145

150

155

160

Ile His Lys Ile Ile Asp Leu Gly Tyr Ala Lys Glu Leu Asp Gln Gly

165

170

175

Ser Leu Cys Thr Ser Phe Val Gly Thr Leu Gln Tyr Leu Ala Pro Glu

180

185

190

Leu Leu Glu Gln Gln Lys Tyr Thr Val Thr Val Asp Tyr Trp Ser Phe

195

200

205

Gly Thr Leu Ala Phe Glu Cys Ile Thr Gly Phe Arg Pro Phe Leu Pro  
210 215 220

Asn Trp Gln Pro Val Gln Trp His Ser Lys Val Arg Gln Lys Ser Glu  
225 230 235 240

Val Asp Ile Val Val Ser Glu Asp Leu Asn Gly Thr Val Lys Phe Ser  
245 250 255

Ser Ser Leu Pro Tyr Pro Asn Asn Leu Asn Ser Val Leu Ala Glu Arg  
260 265 270

Leu Glu Lys Trp Leu Gln Leu Met Leu Met Trp His Pro Arg Gln Arg  
275 280 285

Gly Thr Asp Pro Thr Tyr Gly Pro Asn Gly Cys Phe Lys Ala Leu Asp  
290 295 300

Asp Ile Leu Asn Leu Lys Leu Val His Ile Leu Asn Met Val Thr Gly  
305 310 315 320

Thr Ile His Thr Tyr Pro Val Thr Glu Asp Glu Ser Leu Gln Ser Leu  
325 330 335

Lys Ala Arg Ile Gln Gln Asp Thr Gly Ile Pro Glu Glu Asp Gln Glu  
340 345 350

Leu Leu Gln Glu Ala Gly Leu Ala Leu Ile Pro Asp Lys Pro Ala Thr  
355 360 365

Gln Cys Ile Ser Asp Gly Lys Leu Asn Glu Gly His Thr Leu Asp Met  
370 375 380

Asp Leu Val Phe Leu Phe Asp Asn Ser Lys Ile Thr Tyr Glu Thr Gln  
385 390 395 400

Ile Ser Pro Arg Pro Gln Pro Glu Ser Val Ser Cys Ile Leu Gln Glu

405	410	415
Pro Lys Arg Asn Leu Ala Phe Phe His Leu Arg Lys Val Trp Gly Gln		
420	425	430
Val Trp His Ser Ile Gln Thr Leu Lys Glu Asp Cys Asn Arg Leu Gln		
435	440	445
Gln Gly Gln Arg Ala Ala Met Met Asn Leu Leu Arg Asn Asn Ser Cys		
450	455	460
Leu Ser Lys Met Lys Asn Ser Met Ala Ser Met Ser Gln Gln Leu Lys		
465	470	475 480
Ala Lys Leu Asp Phe Phe Lys Thr Ser Ile Gln Ile Asp Leu Glu Lys		
485	490	495
Tyr Ser Glu Gln Thr Glu Phe Gly Ile Thr Ser Asp Lys Leu Leu Leu		
500	505	510
Ala Trp Arg Glu Met Glu Gln Ala Val Glu Leu Cys Gly Arg Glu Asn		
515	520	525
Glu Val Lys Leu Leu Val Glu Arg Met Met Ala Leu Gln Thr Asp Ile		
530	535	540
Val Asp Leu Gln Arg Ser Pro Met Gly Arg Lys Gln Gly Gly Thr Leu		
545	550	555 560
Asp Asp Leu Glu Glu Gln Ala Arg Glu Leu Tyr Arg Arg Leu Arg Glu		
565	570	575
Lys Pro Arg Asp Gln Arg Thr Glu Gly Asp Ser Gln Glu Met Val Arg		
580	585	590
Leu Leu Leu Gln Ala Ile Gln Ser Phe Glu Lys Lys Val Arg Val Ile		
595	600	605

Tyr Thr Gln Leu Ser Lys Thr Val Val Cys Lys Gln Lys Ala Leu Glu  
 610 615 620

Leu Leu Pro Lys Val Glu Glu Val Val Ser Leu Met Asn Glu Asp Glu  
 625 630 635 640

Lys Thr Val Val Arg Leu Gln Glu Lys Arg Gln Lys Glu Leu Trp Asn  
 645 650 655

Leu Leu Lys Ile Ala Cys Ser Lys Val Arg Gly Pro Val Ser Gly Ser  
 660 665 670

Pro Asp Ser Met Asn Ala Ser Arg Leu Ser Gln Pro Gly Gln Leu Met  
 675 680 685

Ser Gln Pro Ser Thr Ala Ser Asn Ser Leu Pro Glu Pro Ala Lys Lys  
 690 695 700

Ser Glu Glu Leu Val Ala Glu Ala His Asn Leu Cys Thr Leu Leu Glu  
 705 710 715 720

Asn Ala Ile Gln Asp Thr Val Arg Glu Gln Asp Gln Ser Phe Thr Ala  
 725 730 735

Leu Asp Trp Ser Trp Leu Gln Thr Glu Glu Glu Glu His Ser Cys Leu  
 740 745 750

Glu Gln Ala Ser  
 755

(2) INFORMATION FOR SEQ ID NO:10:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 745 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:

(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

Met Glu Arg Pro Pro Gly Leu Arg Pro Gly Ala Gly Gly Pro Trp Glu  
 1                      5                      10                      15

Met Arg Glu Arg Leu Gly Thr Gly Gly Phe Gly Asn Val Cys Leu Tyr  
                     20                      25                      / 30

Gln His Arg Glu Leu Asp Leu Lys Ile Ala Ile Lys Ser Cys Arg Leu  
                     35                      40                      45

Glu Leu Ser Thr Lys Asn Arg Glu Arg Trp Cys His Glu Ile Gln Ile  
                     50                      55                      60

Met Lys Lys Leu Asn His Ala Asn Val Val Lys Ala Cys Asp Val Pro  
 65                      70                      75                      80

Glu Glu Leu Asn Ile Leu Ile His Asp Val Pro Leu Leu Ala Met Glu  
                     85                      90                      95

Tyr Cys Ser Gly Gly Asp Leu Arg Lys Leu Leu Asn Lys Pro Glu Asn  
                     100                      105                      110

Cys Cys Gly Leu Lys Glu Ser Gln Ile Leu Ser Leu Leu Ser Asp Ile  
                     115                      120                      125

Gly Ser Gly Ile Arg Tyr Leu His Glu Asn Lys Ile Ile His Arg Asp  
                     130                      135                      140

Leu Lys Pro Glu Asn Ile Val Leu Gln Asp Val Gly Gly Lys Ile Ile  
 145                      150                      155                      160

His Lys Ile Ile Asp Leu Gly Tyr Ala Lys Asp Val Asp Gln Gly Ser  
165 170 175

Leu Cys Thr Ser Phe Val Gly Thr Leu Gln Tyr Leu Ala Pro Glu Leu  
180 185 190

Phe Glu Asn Lys Pro Tyr Thr Ala Thr Val Asp Tyr Trp Ser Phe Gly  
195 200 205

Thr Met Val Phe Glu Cys Ile Ala Gly Tyr Arg Pro Phe Leu His His  
210 215 220

Leu Gln Pro Phe Thr Trp His Glu Lys Ile Lys Lys Lys Asp Pro Lys  
225 230 235 240

Cys Ile Phe Ala Cys Glu Glu Met Ser Gly Glu Val Arg Phe Ser Ser  
245 250 255

His Leu Pro Gln Pro Asn Ser Leu Cys Ser Leu Ile Val Glu Pro Met  
260 265 270

Glu Asn Trp Leu Gln Leu Met Leu Asn Trp Asp Pro Gln Gln Arg Gly  
275 280 285

Gly Pro Val Asp Leu Thr Leu Lys Gln Pro Arg Cys Phe Val Leu Met  
290 295 300

Asp His Ile Leu Asn Leu Lys Ile Val His Ile Leu Asn Met Thr Ser  
305 310 315 320

Ala Lys Ile Ile Ser Phe Leu Leu Pro Pro Asp Glu Ser Leu His Ser  
325 330 335

Leu Gln Ser Arg Ile Glu Arg Glu Thr Gly Ile Asn Thr Gly Ser Gln  
340 345 350



Glu Leu Leu Ser Glu Thr Gly Ile Ser Leu Asp Pro Arg Lys Pro Ala  
 355 360 365

Ser Gln Cys Val Leu Asp Gly Val Arg Gly Cys Asp Ser Tyr Met Val  
 370 375 380

Tyr Leu Phe Asp Lys Ser Lys Thr Val Tyr Glu Gly Pro Phe Ala Ser  
 385 390 395 400

Arg Ser Leu Ser Asp Cys Val Asn Tyr Ile Val Gln Asp Ser Lys Ile  
 405 410 415

Gln Leu Pro Ile Ile Gln Leu Arg Lys Val Trp Ala Glu Ala Val His  
 420 425 430

Tyr Val Ser Gly Leu Lys Glu Asp Tyr Ser Arg Leu Phe Gln Gly Gln  
 435 440 445

Arg Ala Ala Met Leu Ser Leu Leu Arg Tyr Asn Ala Asn Leu Thr Lys  
 450 455 460

Met Lys Asn Thr Leu Ile Ser Ala Ser Gln Gln Leu Lys Ala Lys Leu  
 465 470 475 480

Glu Phe Phe His Lys Ser Ile Gln Leu Asp Leu Glu Arg Tyr Ser Glu  
 485 490 495

Gln Met Thr Tyr Gly Ile Ser Ser Glu Lys Met Leu Lys Ala Trp Lys  
 500 505 510

Glu Met Glu Glu Lys Ala Ile His Tyr Ala Glu Val Gly Val Ile Gly  
 515 520 525

Tyr Leu Glu Asp Gln Ile Met Ser Leu His Ala Glu Ile Met Glu Leu  
 530 535 540

Gln Lys Ser Pro Tyr Gly Arg Arg Gln Gly Asp Leu Met Glu Ser Leu

545                      550                      555                      560

Glu Gln Arg Ala Ile Asp Leu Tyr Lys Gln Leu Lys His Arg Pro Ser  
565                      570                      575

Asp His Ser Tyr Ser Asp Ser Thr Glu Met Val Lys Ile Ile Val His  
580                      585                      590

Thr Val Gln Ser Gln Asp Arg Val Leu Lys Glu Arg Phe Gly His Leu  
595                      600                      605

Ser Lys Leu Leu Gly Cys Lys Gln Lys Ile Ile Asp Leu Leu Pro Lys  
610                      615                      620

Val Glu Val Ala Leu Ser Asn Ile Lys Glu Ala Asp Asn Thr Val Met  
625                      630                      635                      640

Phe Met Gln Gly Lys Arg Gln Lys Glu Ile Trp His Leu Leu Lys Ile  
645                      650                      655

Ala Cys Thr Gln Ser Ser Ala Arg Ser Leu Val Gly Ser Ser Leu Glu  
660                      665                      670

Gly Ala Val Thr Pro Gln Ala Tyr Ala Trp Leu Ala Pro Asp Leu Ala  
675                      680                      685

Glu His Asp His Ser Leu Ser Cys Val Val Thr Pro Gln Asp Gly Glu  
690                      695                      700

Thr Ser Ala Gln Met Ile Glu Glu Asn Leu Asn Cys Leu Gly His Leu  
705                      710                      715                      720

Ser Thr Ile Ile His Glu Ala Asn Glu Glu Gln Gly Asn Ser Met Met  
725                      730                      735

Asn Leu Asp Trp Ser Trp Leu Thr Glu  
740                      745

## (2) INFORMATION FOR SEQ ID NO:11:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 22 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

Cys Lys Lys Glu Arg Leu Leu Asp Asp Arg His Asp Ser Gly Leu Asp  
1                    5                    10                    15  
  
Ser Met Lys Asp Glu Glu  
                    20

## (2) INFORMATION FOR SEQ ID NO:12:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 22 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:12:

Cys Lys Lys Glu Arg Leu Leu Asp Asp Arg His Asp Thr Gly Leu Asp  
1                    5                    10                    15

Thr Met Lys Asp Glu Glu

20

(2) INFORMATION FOR SEQ ID NO:13:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 19 amino acids

(B) TYPE: amino acid

(C) STRANDEDNESS:

(D) TOPOLOGY: linear

(ix) FEATURE:

(A) NAME/KEY: Modified-site

(B) LOCATION: 10

(D) OTHER INFORMATION: /note= "Where Xaa is a Phosphate  
Ester of Threonine"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:13:

Asp Leu Thr Gly Gly Pro Glu Val Ala Xaa Pro Glu Ser Glu Glu Ala  
1                      5                      10                      15

Phe Leu Pro

(2) INFORMATION FOR SEQ ID NO:14:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 19 amino acids

(B) TYPE: amino acid

(C) STRANDEDNESS:

(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:14:

Cys	Pro	Thr	Asn	Ser	Ala	Leu	Asn	Tyr	Leu	Lys	Ser	Pro	Ile	Thr	Thr
1				5					10					15	
Ser Pro Ser															

(2) INFORMATION FOR SEQ ID NO:15:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 15 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:15:

Cys	Asn	Ser	Asp	Leu	Leu	Thr	Ser	Pro	Asp	Val	Gly	Leu	Leu	Lys
1				5					10					15

(2) INFORMATION FOR SEQ ID NO:16:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 15 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:16:

Cys	Val	Gly	Leu	Leu	Lys	Leu	Ala	Ser	Pro	Glu	Leu	Glu	Arg	Leu
1				5					10					15

(2) INFORMATION FOR SEQ ID NO:17:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 8 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS:
  - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:17:

Ile	Ile	Asp	Leu	Gly	Tyr	Ala	Lys
1				5			

(2) INFORMATION FOR SEQ ID NO:18:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 9 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS:
  - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:18:

Val Glu Val Ala Leu Ser Asn Ile Lys  
1 5

(2) INFORMATION FOR SEQ ID NO:19:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 8 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:19:

Ser Ile Gln Leu Asp Leu Glu Arg  
1 5

(2) INFORMATION FOR SEQ ID NO:20:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 7 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:20:

Ala Leu Glu Leu Leu Pro Lys

1 5

(2) INFORMATION FOR SEQ ID NO:21:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 8 amino acids

(B) TYPE: amino acid

(C) STRANDEDNESS:

(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:21:

Val Ile Tyr Thr Gln Leu Ser Lys

1 5

(2) INFORMATION FOR SEQ ID NO:22:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 11 amino acids

(B) TYPE: amino acid

(C) STRANDEDNESS:

(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:22:

Leu Leu Leu Gln Ala Ile Gln Ser Phe Glu Lys

1 5 10



## (2) INFORMATION FOR SEQ ID NO:23:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 11 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:23:

Leu Gly Thr Gly Gly Phe Gly Asn Val Ile Arg  
1                      5                      10

## (2) INFORMATION FOR SEQ ID NO:24:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 9 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:24:

Ala Leu Asp Asp Ile Leu Asn Leu Lys  
1                      5

## (2) INFORMATION FOR SEQ ID NO:25:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 15 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS:
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:25:

Asp	Leu	Lys	Pro	Glu	Asn	Ile	Val	Leu	Gln	Gln	Gly	Glu	Gln	Arg
1				5					10					15

Claims

1. An IKK signalsome capable of specifically phosphorylating I $\kappa$ B $\alpha$  at residues S32 and S36, and I $\kappa$ B $\beta$  at residues 19 and 23, without the addition of exogenous cofactors.
2. An IKK signalsome according to claim 1 wherein the signalsome is derived from a human tissue or cell line.
3. A polypeptide comprising a component of an IKK signalsome according to claim 1, or a variant of such a component, wherein the component has a sequence recited in SEQ ID NO:9.
4. An isolated DNA molecule encoding a polypeptide according to claim 3.
5. A recombinant expression vector comprising a DNA molecule according to claim 4.
6. A host cell transformed or transfected with an expression vector according to claim 5.
7. A host cell according to claim 6, wherein the host cell is selected from the group consisting of bacteria, yeast, baculovirus infected insect cells and mammalian cells.
8. A method for preparing an IKK signalsome, comprising combining components of an IKK signalsome in a suitable buffer.

9. A method for phosphorylating a substrate of an IKK signalsome, comprising contacting a substrate with a signalsome according to claim 1 and thereby phosphorylating the substrate.

10. A method for phosphorylating a substrate of an IKK signalsome, comprising contacting a substrate with a polypeptide comprising a component of an IKK signalsome having I $\kappa$ B kinase activity, and thereby phosphorylating the substrate.

11. A method according to claim 10, wherein the polypeptide comprises IKK-1 (SEQ ID NO:10).

12. A method according to claim 10, wherein the polypeptide comprises IKK-2 (SEQ ID NO:9).

13. The method of either of claims 9 or 10, wherein the substrate is I $\kappa$ B $\alpha$  or a variant thereof.

14. A method for screening for an agent that modulates IKK signalsome activity, comprising:

(a) contacting a candidate agent with an IKK signalsome according to claim 1, wherein the step of contacting is carried out under conditions and for a time sufficient to allow the candidate agent and the IKK signalsome to interact; and

(b) subsequently measuring the ability of the candidate agent to modulate a IKK signalsome activity.

15. A method according to claim 14, wherein the IKK signalsome activity modulated is selected from the group consisting of I $\kappa$ B kinase activity, p65 kinase activity and IKK phosphatase activity.

16. A method for screening for an agent that modulates IKK signalsome activity, comprising:

(a) contacting a candidate agent with a polypeptide comprising a component of an IKK signalsome according to claim 1, wherein the step of contacting is carried out under conditions and for a time sufficient to allow the candidate agent and the polypeptide to interact; and

(b) subsequently measuring the ability of the candidate agent to modulate the ability of the polypeptide to phosphorylate an I $\kappa$ B protein.

17. A method according to claim 16, wherein the polypeptide comprises IKK-1 (SEQ ID NO:10).

18. A method according to claim 16, wherein the polypeptide comprises IKK-2 (SEQ ID NO:9).

19. An antibody that binds to IKK-1 (SEQ ID NO:10) and/or IKK-2 (SEQ ID NO:9).

20. An antibody according to claim 19, wherein the antibody inhibits the phosphorylation of an I $\kappa$ B protein by an IKK signalsome.

21. A composition comprising an agent that modulates IKK signalsome activity in combination with a pharmaceutically acceptable carrier, for use in the manufacture of a medicament for modulating NF- $\kappa$ B activity in a patient.

22. The composition of claim 21, wherein the agent inhibits activation of an IKK signalsome.

23. The composition of claim 21, wherein the agent inhibits kinase activity of an activated IKK signalsome.

24. A composition comprising an agent that modulates IKK signalsome activity in combination with a pharmaceutically acceptable carrier, for use in

the manufacture of a medicament for treating a patient afflicted with a disorder associated with the activation of an IKK signalsome.

25. The composition of any one of claims 21-24, wherein the agent is a monoclonal antibody.

26. The composition of any one of claims 21-24, wherein the agent comprises a polynucleotide.

27. A method for detecting IKK signalsome activity in a sample, comprising:

- (a) contacting a sample with an antibody that binds to an IKK signalsome under conditions and for a time sufficient to allow the antibody to immunoprecipitate an IKK signalsome;
- (b) separating immunoprecipitated material from the sample; and
- (c) determining the ability of the immunoprecipitated material to phosphorylate an I $\kappa$ B protein with *in vivo* specificity.

28. A method according to claim 27, wherein the immunoprecipitated material phosphorylates I $\kappa$ B $\alpha$  at residues S32 and S36.

29. A kit for detecting IKK signalsome activity in a sample, comprising an antibody that binds to a IKK signalsome in combination with a suitable buffer.

30. A method for identifying an upstream kinase in the NF- $\kappa$ B signal transduction cascade, comprising evaluating the ability of a candidate upstream kinase to phosphorylate and induce enzymatic activity of an IKK signalsome or a component or variant thereof, and thereby identifying an upstream kinase in the NF- $\kappa$ B signal transduction cascade.

31. A method for identifying a component of an IKK signalsome, comprising:

- (a) isolating an IKK signalsome;
- (b) separating the signalsome into components; and
- (c) obtaining a partial sequence of a component, and thereby identifying a component of an IKK signalsome.

32. A method for preparing an IKK signalsome from a biological sample, comprising:

- (a) separating a biological sample into two or more fractions; and
- (b) monitoring I $\kappa$ B kinase activity in the fractions.

Figure 1A

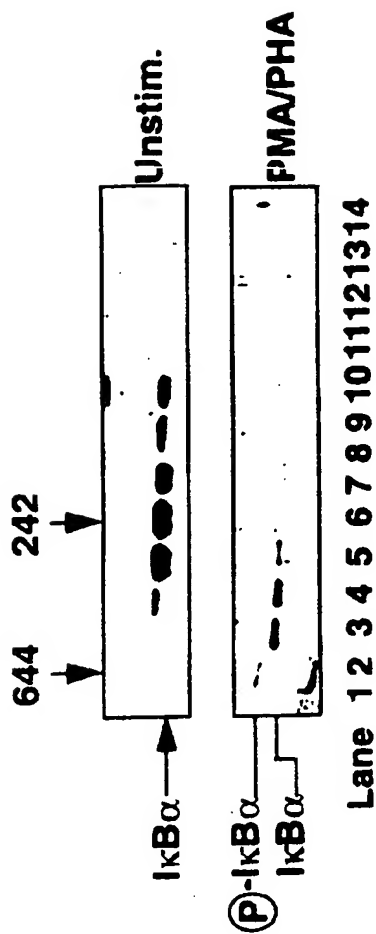
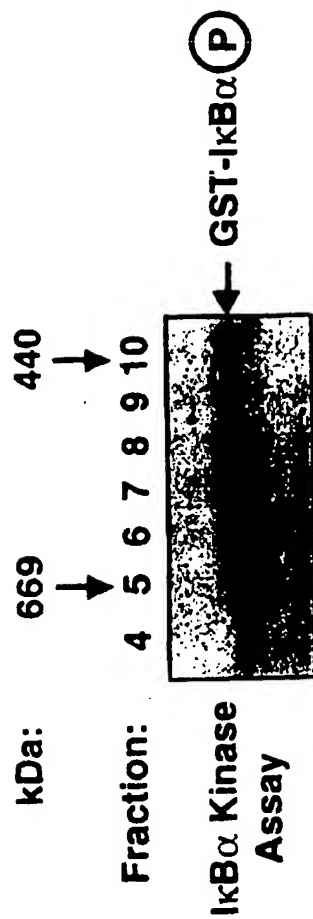


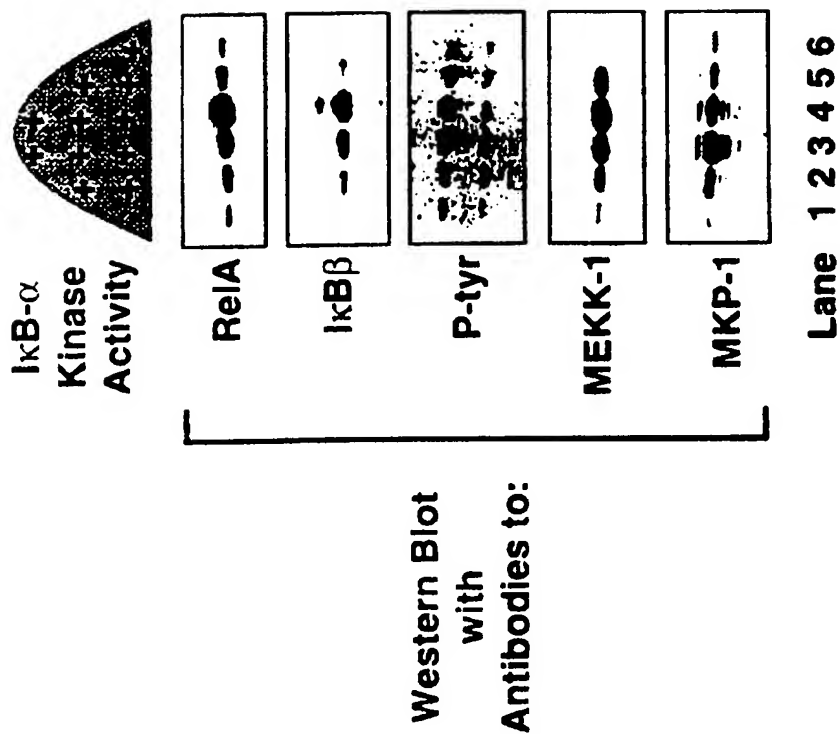


Figure 1B



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Figure 1C



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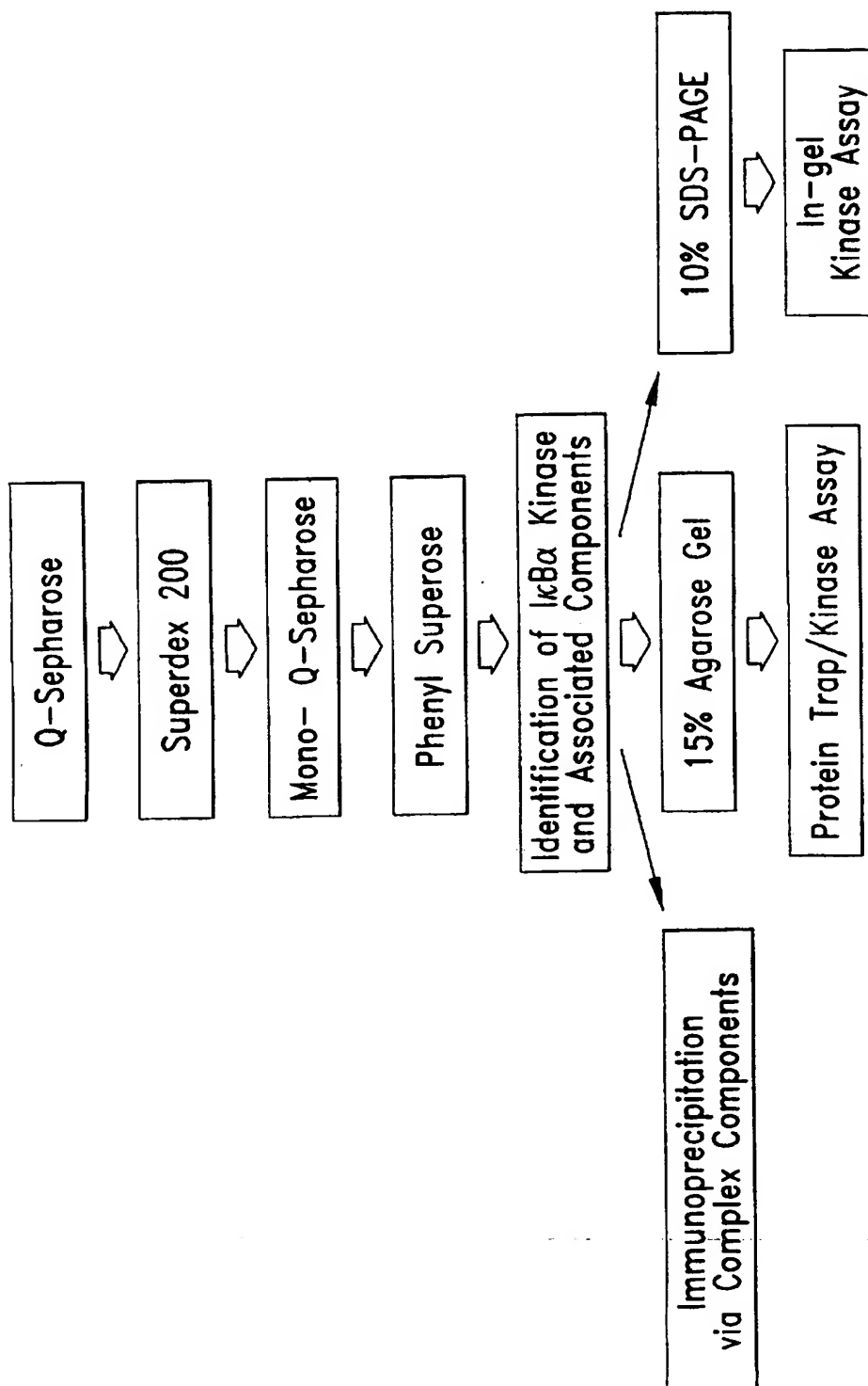
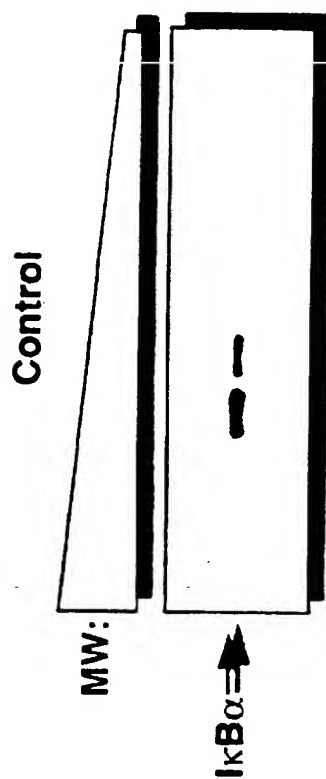
**Figure 2**

Figure 3A



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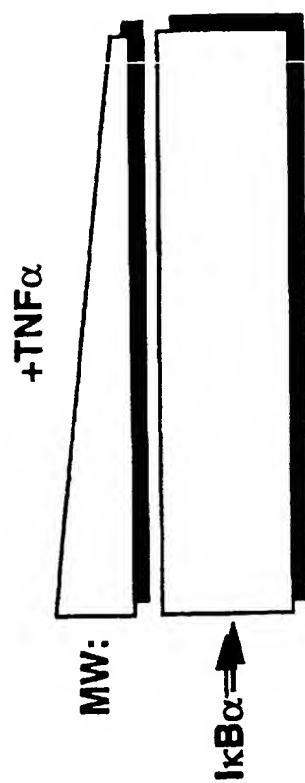
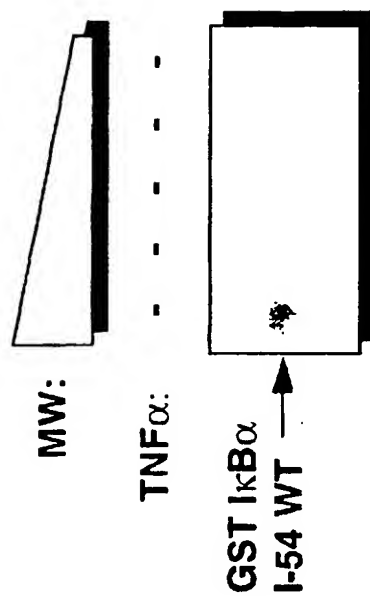


Figure 3B

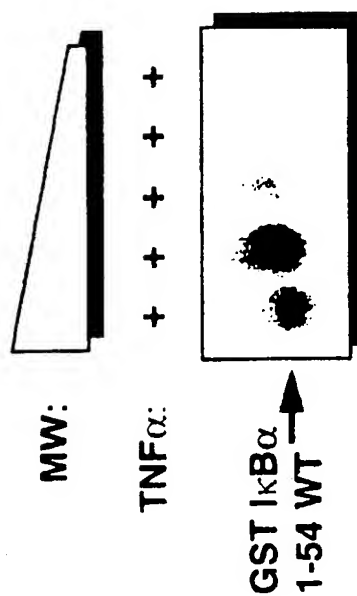
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Figure 4A



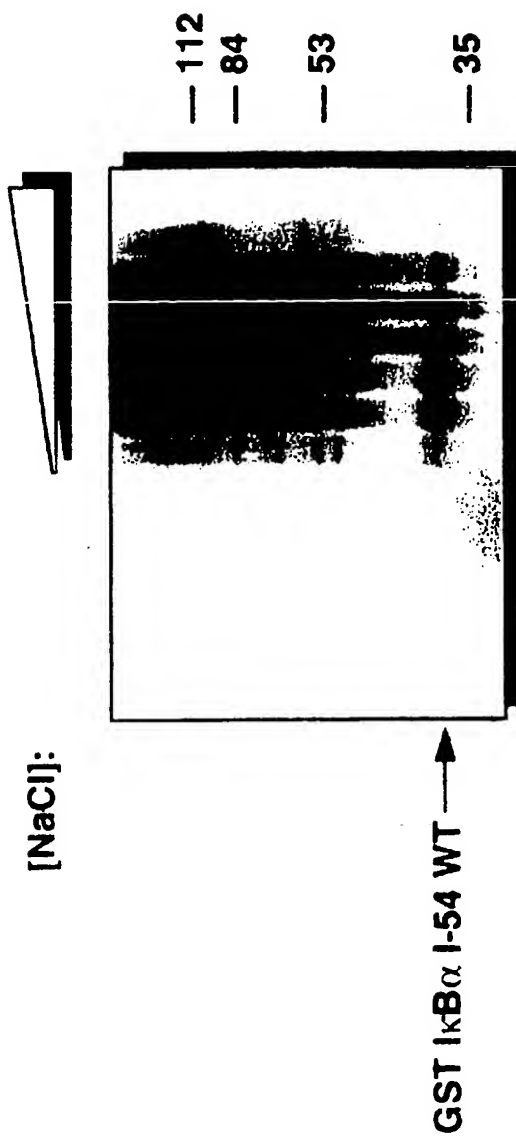
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Figure 4B



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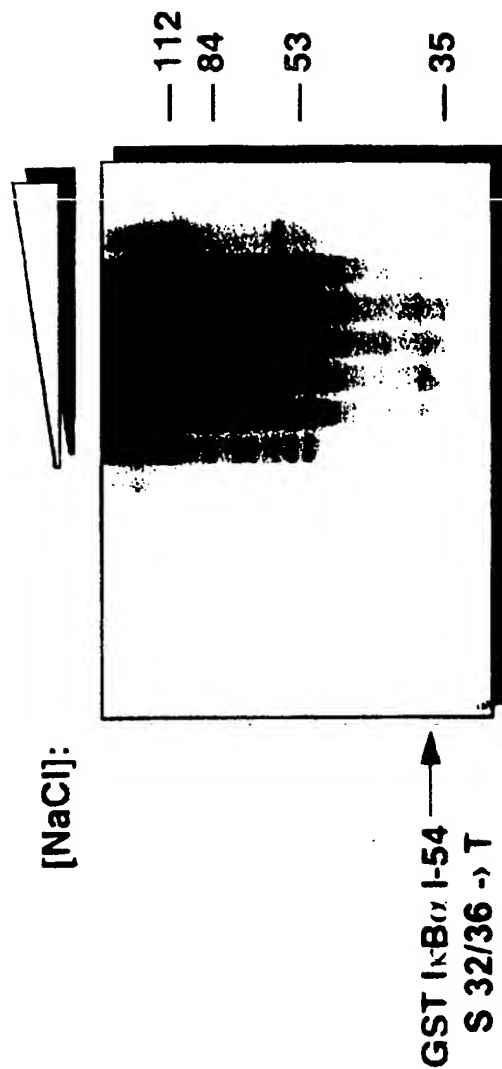
Figure 5A





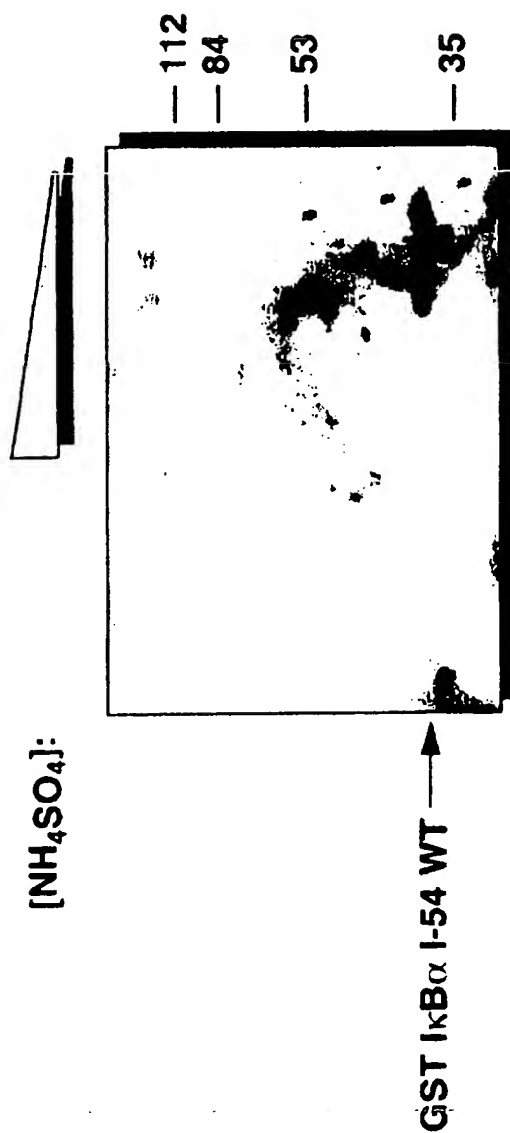
10/30

Figure 5B



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Figure 6A



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Figure 6B

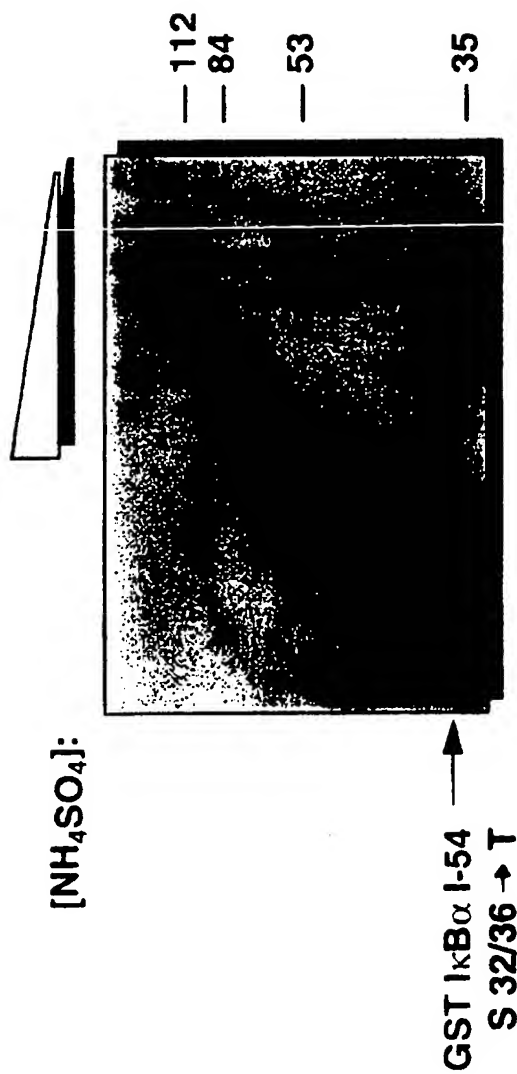


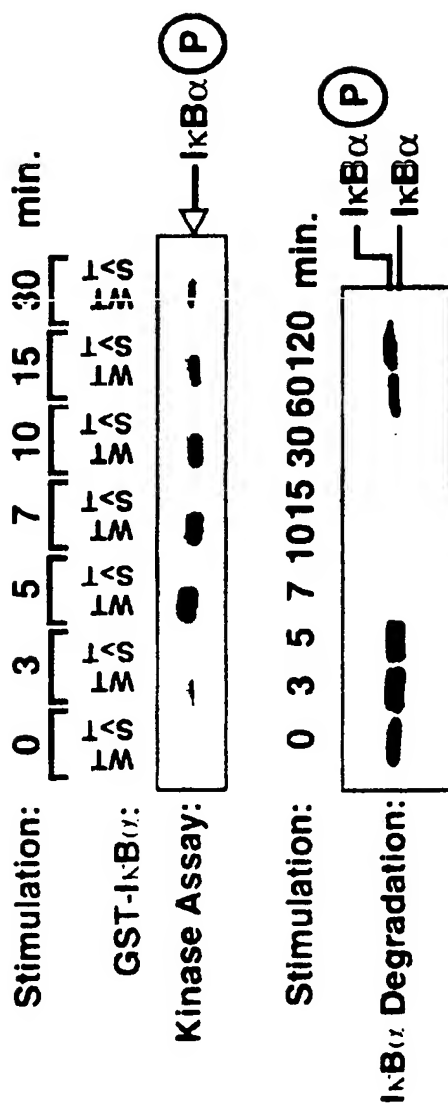
Figure 7

GST-IkB $\alpha$  1-54 WT  
GST-IkB $\alpha$  1-54 S32/36 to T

GST-IkB $\alpha$  1-54 →

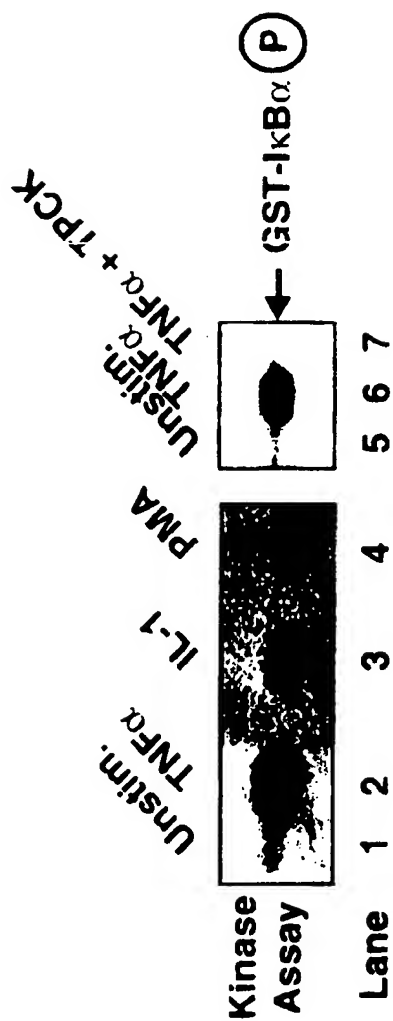
14/30

Figure 8A



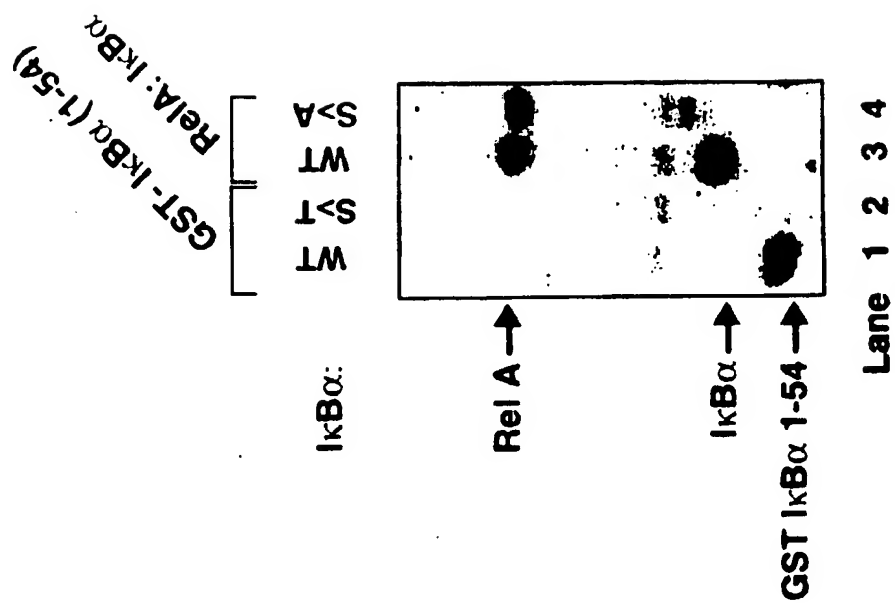
15/30

Figure 8B



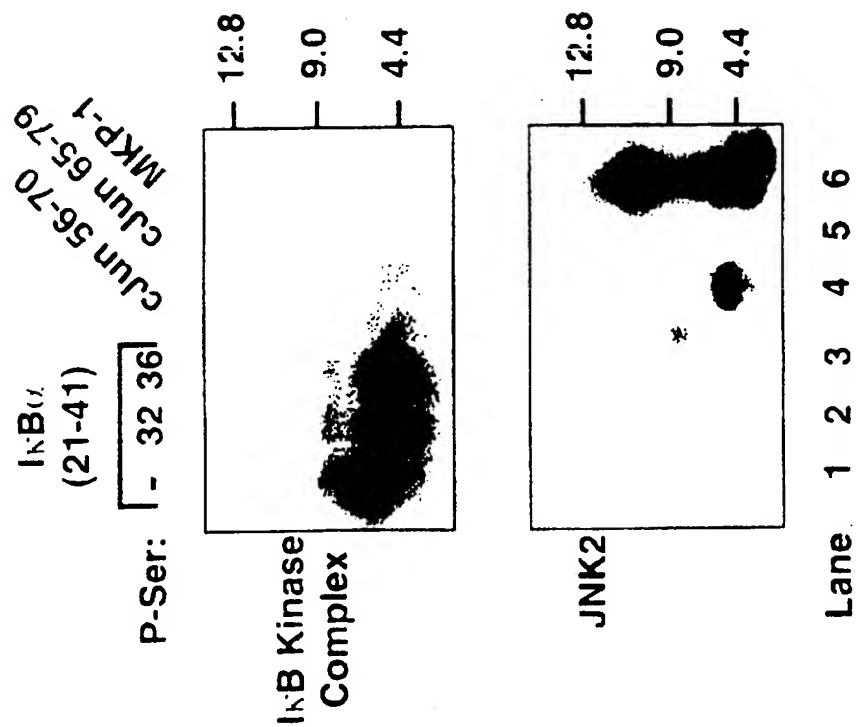
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Figure 8C



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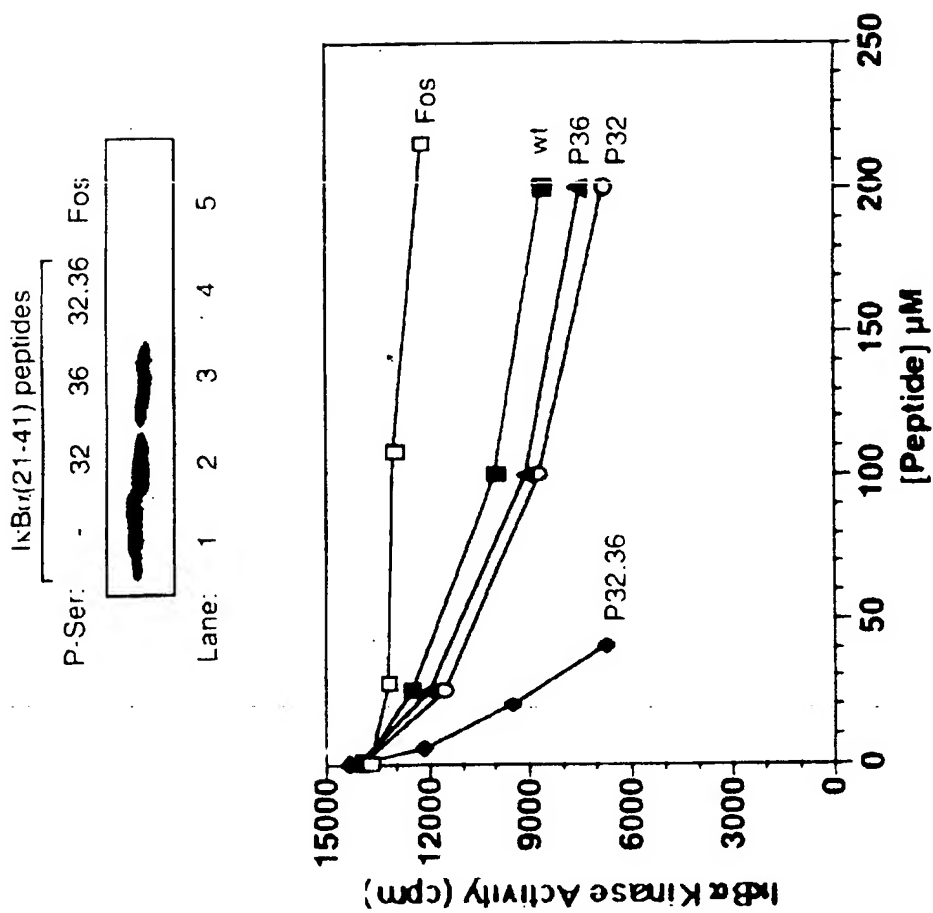
Figure 9A





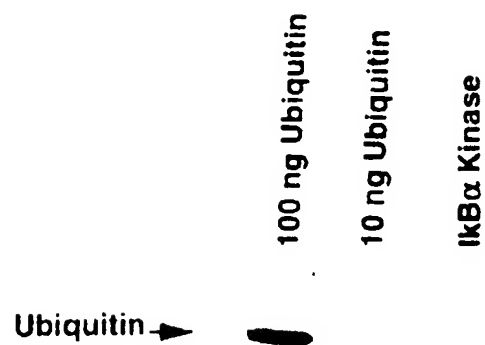
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Figure 9B

Interactions of I $\kappa$ B $\alpha$  Peptides with the Signosome

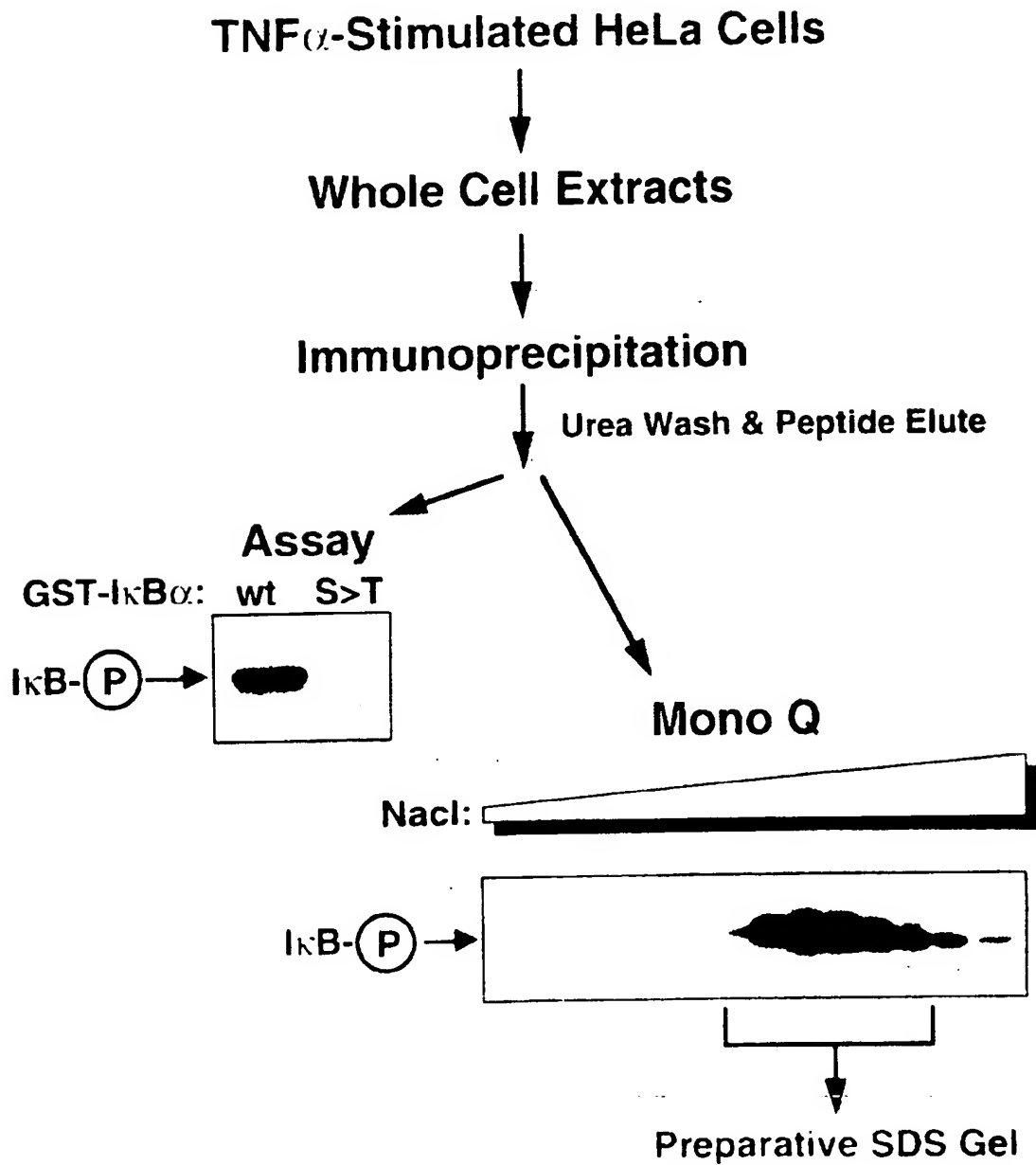
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## Figure 10



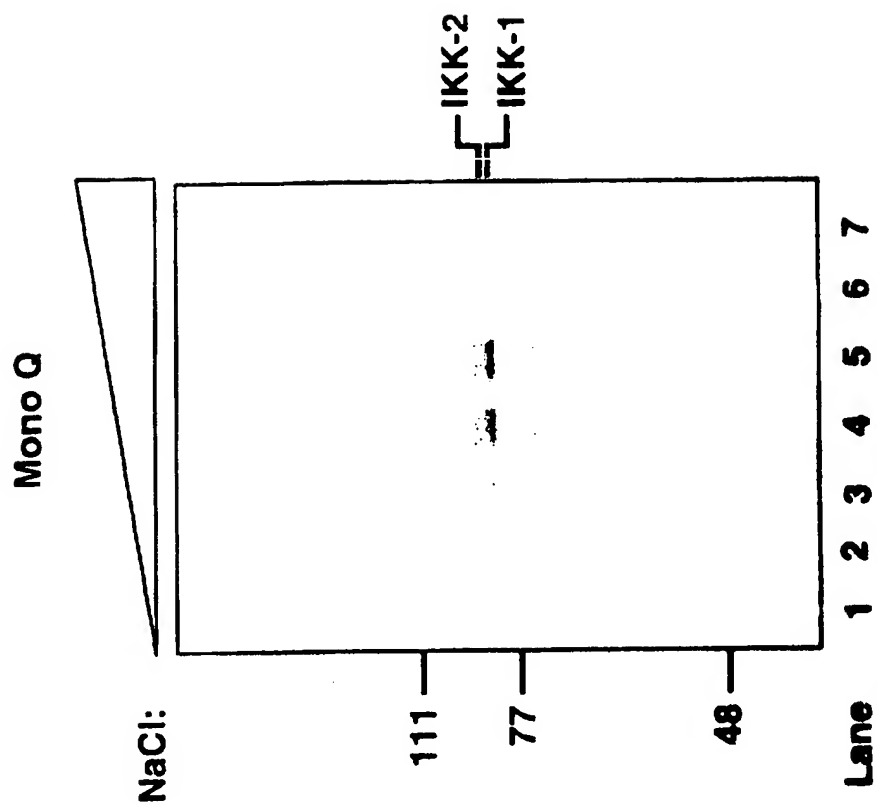
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Figure 11A



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Figure 11B



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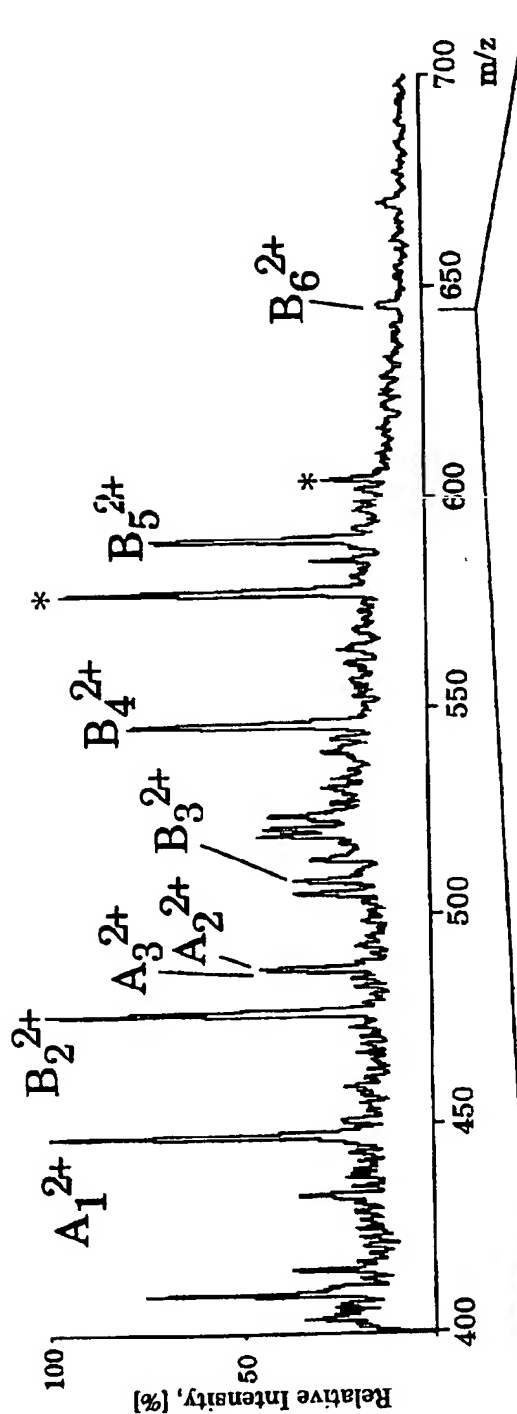


Figure 12A

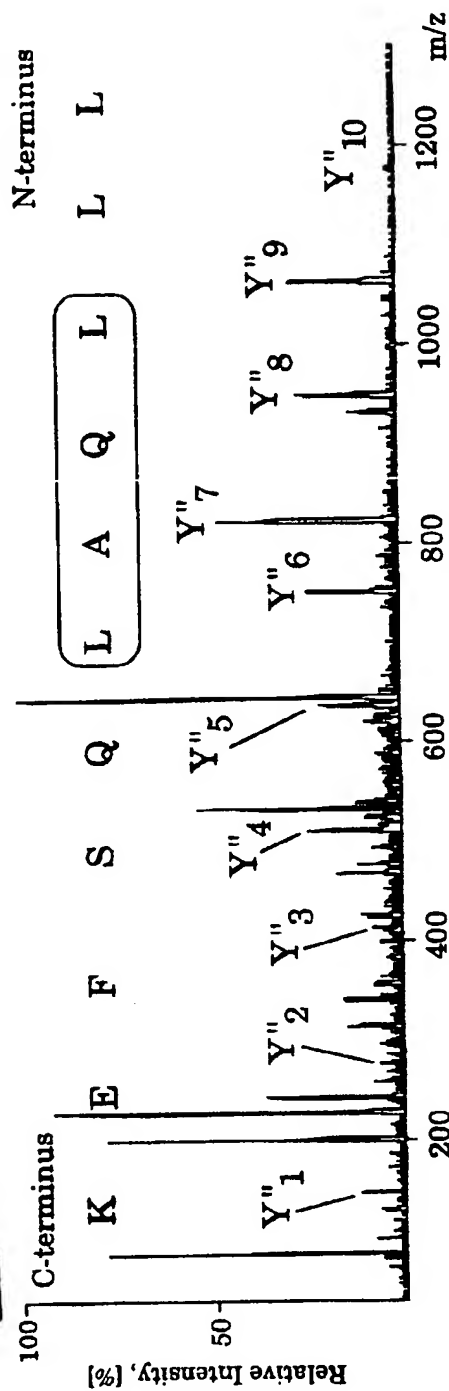


Figure 12B

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	10	20	30	40	50	
IKK-1	H E R P P G L R P G A G G P	W E N R E R L G T G G F G N V C L Y Q H R E L D L K I A I K S C R L E L				
IKK-2	N S W S P S L T T Q T C G A	W E N K E R L G T G G F G N V I R W H N Q E T G E Q I A I K Q C R Q E L				
	60	70	80	90	100	
IKK-1	S T K N R E R W C H E I Q I M K K L N H A N V V K A C D V P E E L N - I L I H D V P L L A M E Y C S					
IKK-2	S P R N R E R W C L E I Q I M R R L T H P N V V A A R D V P E G M Q N L A P N D L P L L A M E Y C Q					
	110	120	130	140	150	
IKK-1	G G D L R K L L N K P E N C C G L K E S Q I L S L L S D I G S G I R Y L H E N K I I H R D L K P E N					
IKK-2	G G D L R K Y L N Q F E N C C G L R E G A I L T L L S D I A S A L R Y L H E N R I I H R D L K P E N					
	160	A1	170	180	190	200
IKK-1	I V L Q D V G G K I I H K I I D L G Y A K D V D Q G S L C T S F V G T L Q Y L A P E L F E N K P Y T					
IKK-2	I V L Q Q G E Q R L I H K I I D L G Y A K E L D Q G S L C T S F V G T L Q Y L A P E L L E Q Q K Y T					
	210	220	230	240	250	
IKK-1	A T V D Y W S F G T M V F E C I A G Y R P F L H H L Q P F T W H E K I K K K D P K C I F A C E E M S					
IKK-2	V T V D Y W S F G T L A F E C I T G F R P F L P N W Q P V Q W H S K V R Q K S E V D I V V S E D L N					
	260	270	280	290	300	
IKK-1	G E V R F S S H L P Q P N S L C S L I V E P H E N W L Q L M L N W D P Q Q R G G P V D L T L K Q P R					
IKK-2	G T V K F S S S L P Y P N N L N S V L A E R L E K W L Q L M L M W H P R O R G - - T D P T Y G P N G					
	310	320	330	340	350	
IKK-1	CFV L M D H I L N L K I V H I L N M T S A K I I S F L L P P D E S L H S L Q S R I E R E T G I N T					
IKK-2	CFK A L D D I L N L K L V H I L N M V T G T I H T Y P V T E D E S L Q S L K A R I Q Q D T G I P E					
	360	370	380	390	400	
IKK-1	G S Q E L L S E T G I S L D P R K P A S Q C V L D G - - - V R G C D S Y M V Y L F D K S K T V Y E					
IKK-2	E D Q E L L Q E A G L A L I P D K P A T Q C I S D G K L N E G H T L D M D L V F L F D N S K I T Y E					
	410	420	430	440	450	
IKK-1	G P F A S R S L S D C V N Y I V Q D S K I Q L P I I Q L R K V W A E A V H Y V S G L K E D Y S R L F					
IKK-2	T Q I S P R P Q P E S V S C I L Q E P K R N L A F F H L R K V W G Q V W H S I Q T L K E D C N R L O					

Figure 13A-1

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	460	470	480	490	A3	500
IKK-1	Q G Q R A A N L S	L L R Y N A N L T K M K N T L I S A S Q Q L K A K L E F	F H K S I Q L D L E R Y S			
IKK-2	Q G Q R A A M M N	L L R N N S C L S K M K N S M A S M S Q Q L K A K L D F	F K T S I Q I D L E K Y S			

	510	520	530	540	550
IKK-1	E Q M T Y G I S S E K M L K A W K E M E E K A I H Y A E V G V I G Y L E D Q I M S L H A E I M E L Q				
IKK-2	E Q T E F G I T S D K L L L A W R E M E Q A V E L C G R E N E V K L L V E R M M A L Q T D I V D L Q				

	560	570	580	590	B3	600
IKK-1	K S P Y G R R Q G D L M E S L E Q R A I D L Y K Q L K H R P S D - H S Y S D S T E M V K I I V H T V					
IKK-2	R S P M G R K Q G G T L D D L E E Q A R E L Y R R L R E K P R D Q R T E G D S Q E M V R L L L Q A I					

	610	B2	620	B1	630	A2	640	650
IKK-1	Q S Q D R V	L K E R F G H L S K L L G C K Q K I I D L L P K V E V A L S N I K E A D N T V M	F M Q G					
IKK-2	Q S F E K K	V R V I Y T Q L S K T V V C K Q K A L E L L P K V E E V V S L M N E D E K T V V	R L Q E					

	660	670	680	690	700
IKK-1	K R Q K E I W H L L K I A C T Q S S A R S L V G S S L E G A V T P Q A Y A W L A P D L A E H D H S L				
IKK-2	K R Q K E L W N L L K I A C S K - - V R G P V S G S P D - - - S M N A S R L S Q P G Q L M S Q P S T				

	710	720	730	740	750
IKK-1	S C V V T P Q D G E T S A Q M I E E N L N C L G H L S T I I H E A N E E Q G N S M M N L D W S W L T				
IKK-2	A S N S L P E P A K K S E E L V A E A H N L C T L L E N A I Q D T V R E Q D Q S F T A L D W S W L Q				

	751	763
IKK-1	E	
IKK-2	T E E E E H S C L E Q A S	

Figure 13A-2

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Figure 13B

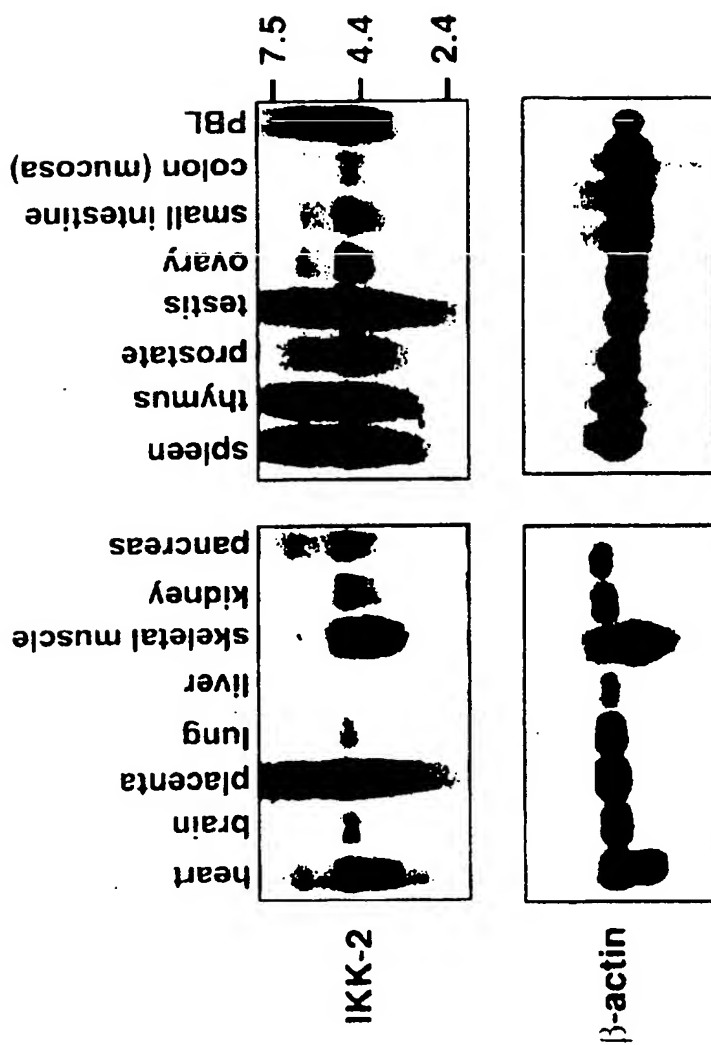
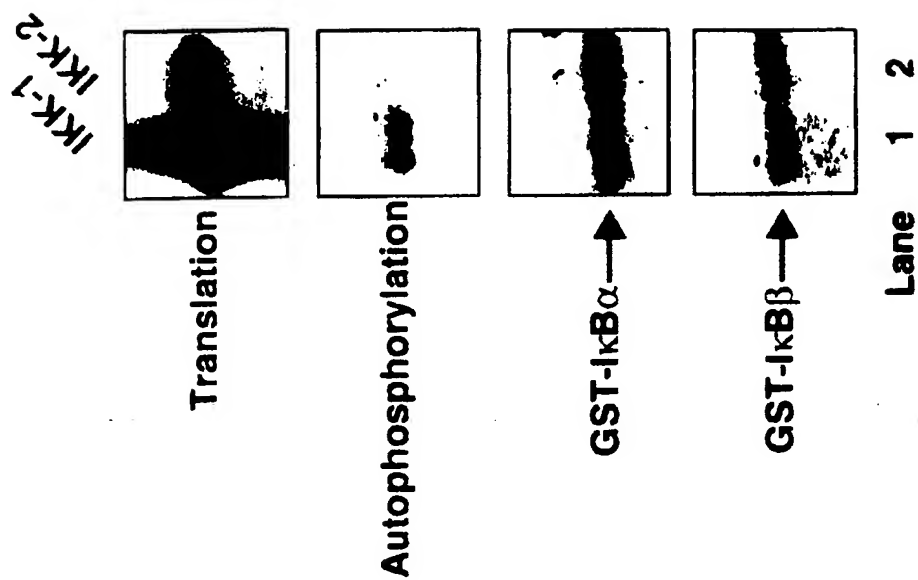




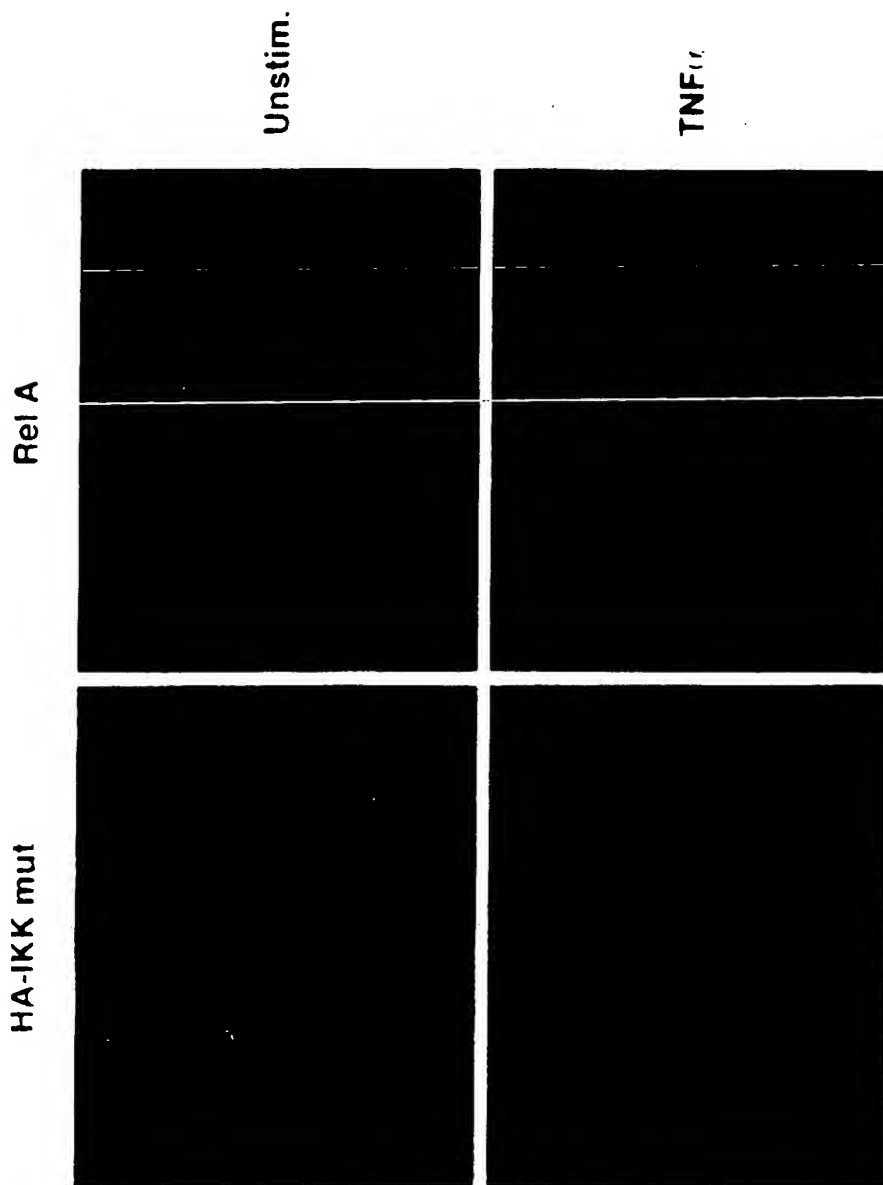
Figure 14A



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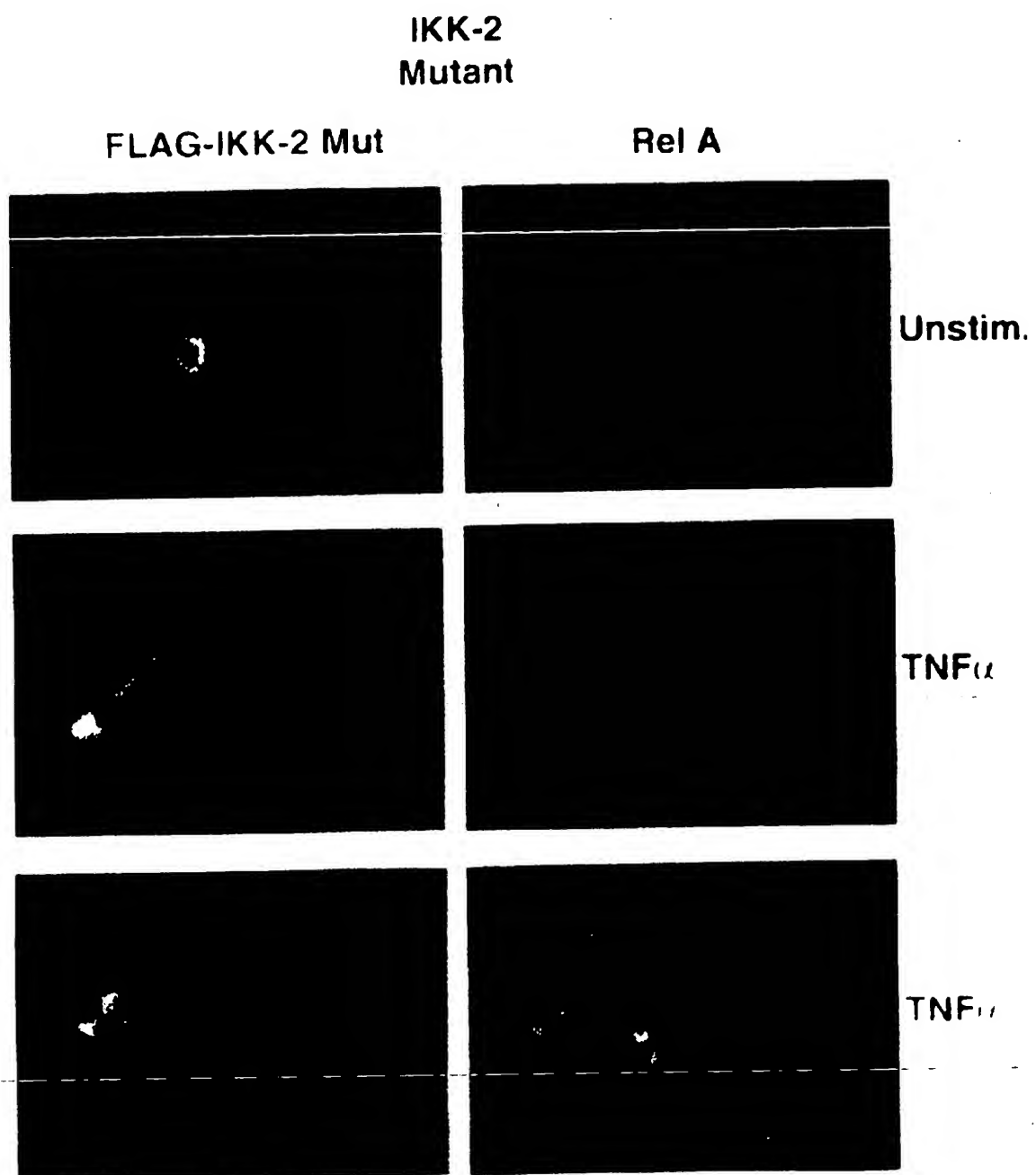
Figure 14B

IKK-1  
Mutant



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Figure 14C



**Figure 15A**

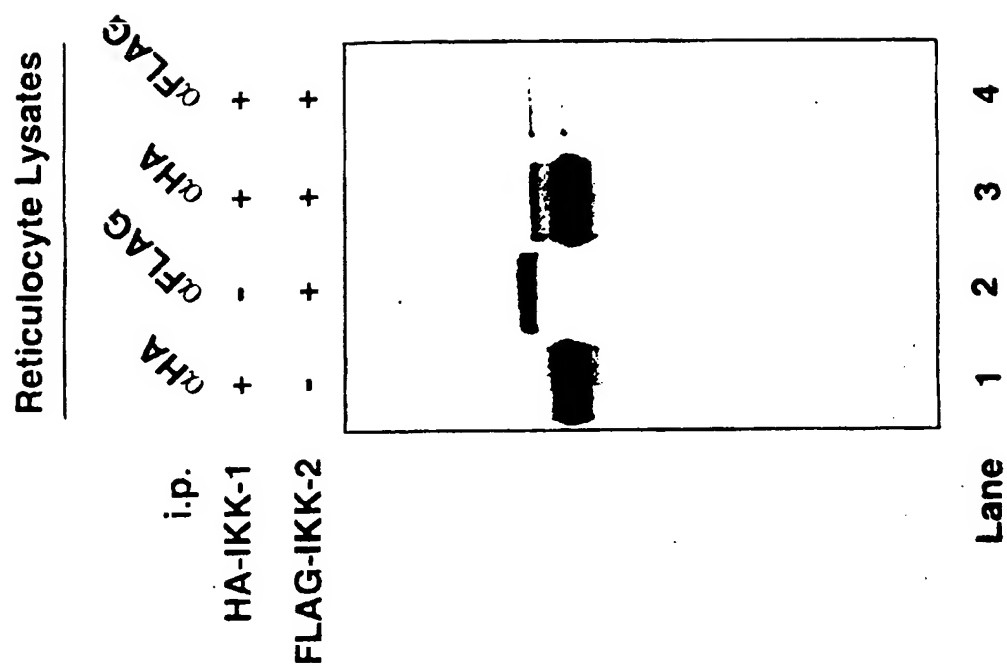
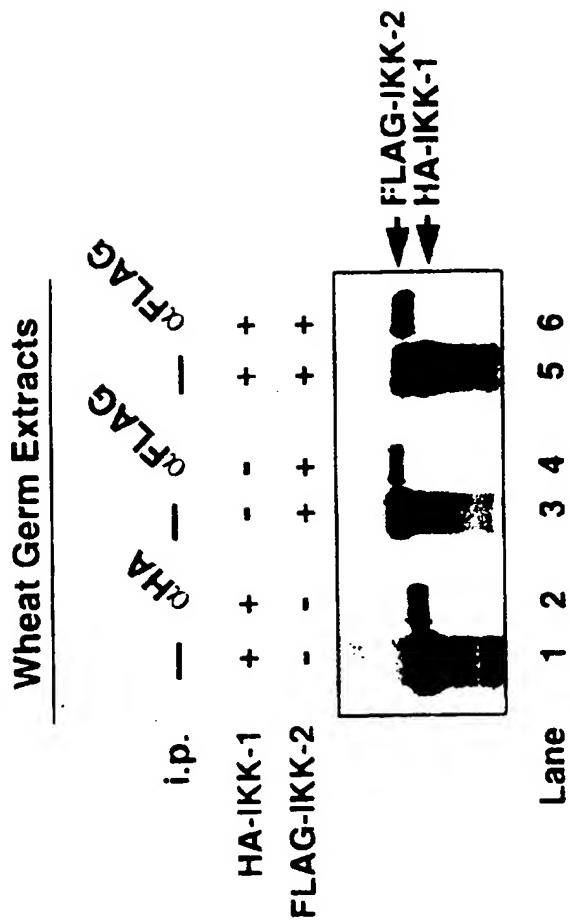


Figure 15B



# INTERNATIONAL SEARCH REPORT

International Application No.

PCT/US 97/15003

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 C12N15/54 C12N9/12 C12Q1/48 C07K16/40 A61K38/45  
C07K14/47 C12N5/10 G01N33/573 C12N15/12

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C12N C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CHEN Z.J. ET AL.: "Site-specific phosphorylation of I(kappa)B(alpha) by a novel ubiquitination-dependent protein kinase activity." CELL, vol. 84, 22 March 1996, pages 853-862, XP002037788 cited in the application	1,2, 8-10, 14-16, 21-29, 31,32
Y	see abstract see page 855, column 1, paragraph 2 see page 856, column 1, paragraph 4 --- -/--	3-7,12, 18



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

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Date of the actual completion of the international search

26 January 1998

Date of mailing of the international search report

06/02/1998

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NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 97/15003

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	<p>RÉGNIER C.H. ET AL.: "Identification and characterization of an I(kappa)B kinase." CELL, vol. 90, 25 July 1997, pages 373-383, XP002053258 see abstract see page 376, column 1, paragraph 3 - column 2, paragraph 1 see page 377, column 2, line 7 - line 11 see page 380, column 2, paragraph 3 see page 375; figure 1</p>	<p>1,2, 8-11, 13-17, 19-33</p>
P,X	<p>DIDONATO J.A. ET AL.: "A cytokine-responsive I(kappa)B kinase that activates the transcription factor NF-(kappa)B" NATURE, vol. 388, 7 August 1997, pages 548-554, XP002053259</p>	<p>1,2, 8-11, 13-17, 19-29, 31,32</p>
Y	<p>see abstract see page 548, column 2, paragraph 4 - page 549, column 1, paragraph 1 see page 550; figure 3</p>	<p>3-7,12, 18</p>
E	<p>WO 97 35014 A (PROSCRIPT INC) 25 September 1997  see abstract see example 2 see examples 10-15 see example 16 see claims 1-42</p>	<p>1,2, 8-10, 13-17, 21-32</p>
T	<p>ISRAËL A.: "I(kappa)B kinase all zipped up." NATURE, vol. 388, 7 August 1997, pages 519-521, XP002053260 see the whole document</p>	
T	<p>MANIATIS T.: "Catalysis by a multiprotein I(kappa)B kinase complex." SCIENCE, vol. 278, 31 October 1997, pages 818-819, XP002053261 see the whole document</p>	

# INTERNATIONAL SEARCH REPORT

**Information on patent family members**

Internal Application No

**PCT/US 97/15003**

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9735014 A	25-09-97	AU 2531797 A	10-10-97



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**Summary**

Document	Pages	Printed	Missed
WO009837228	102	102	0
WO009808955	116	116	0
Total (2)	218	218	0